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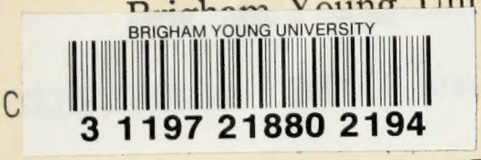

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The Metallurgy of Iron.

Prepared for the Use of the Students

of the

Massachusetts Institute of Technology,

Boston, Mass.,

by

Robert Hallowell 1844

Prof. R. H. Richards, Editor.

J. W. Cabot.

R. H. Sweetser.

W. A. Tucker.

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The World's Production of Pig Iron (in metric tons)

(From "The Mineral Industry", 1893. [Chapt. on Iron & Steel.])

Countries	1865.	1870.	1875.	1880.	1885.	1890.	1892.	1893.	Percent of World's Production, 1892	
United States.	843,410	1,692,378	2,056,750	3,897,840	4,110,600	9,353,020	9,304,428	7,239,206	U.S.	34.64%
United Kingdom	4,897,971	6,060,720	6,469,219	7,875,545	7,368,842	8,033,052	6,817,274		United King.	25.37
Germany	988,191	1,391,123	2,029,389	2,792,038	3,687,434	4,658,451	4,937,461	4,953,148	Ger.	18.38
France	1,203,710	1,178,113	1,448,272	1,725,293	1,630,648	1,962,196	2,022,989		Fr.	7.53
Austria-Hungary	101,403	402,953	463,063	464,234	714,787	965,382	940,284		Aus.-Hung.	3.50
Russia.	299,438	359,531*	427,187	448,596	528,170	927,585	919,614*		Rus.	3.42
Belgium.	470,767	565,234	541,805	608,084	712,876	787,836	753,268	760,296	Bel.	2.80
Sweden.	226,619	300,338	350,539	405,713	464,737	456,103	485,664	760,296	Sw.	1.80
Spain.	——	——	——	85,939	159,225	170,782	247,329	260,450	Sp.	0.92
Canada.	——	——	——	——	——	——	38,514		Can.	0.14
Italy.	——	——	——	——	15,991	14,346	12,729		Italy	0.05
All Other Countries	68,037	309,520	316,078	306,946	398,583	301,959	350,000*		all other countries	1.30
Total.	9,099,666	12,259,910	14,102,222	18,547,228	19,791,893	27,630,712	26,859,554		Percent. calculated from accompanying table.	

* No official record – estimates based upon authoritative figures.

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Mineral Products of the United States.

(from "Mineral Resources of U.S." - 1893 - David T. Day.)

Products.	1880.		1885.		1890.		1892.		1893.	
Metals.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity	Value.	Quantity	Value.
Pig Iron, {value at Philadelphia - long tons	3,375,912	$ 89,315,569	4044,425	$ 64,712,400	9,202,703	$ 151,200,410	9,157,000	$ 131,161,039	7,124,502	$ 84,810,426
Silver, coining value - Troy oz.	30,320,000	39,200,000	39,910,279	51,600,000	54,500,000	70,464,645	63,500,000	82,079,150	60,000,000	77,575,757
Gold, coining value - Troy ozs.	1,741,500	36,000,000	1,538,376	31,800,000	1,588,880	32,845,000	1,596,375	33,000,000	1,739,323	35,955,000
Copper - value at New York, - lbs.	60,480,000	11,491,200	170,962,607	18,292,999	265,115,133	30,848,797	353,275,142	37,977,142	337,416,848	32,054,601
Lead - " " " " short tons.	97,825	9,782,500	129,412	10,469,431	143,680	12,668,166	173,654	13,822,320	163,982	11,889,590
Zinc - " " " " " "	23,239	2,277,432	40,688	3,539,856	63,683	6,266,407	87,260	8,027,920	78,832	6,306,560
Quicksilver - val. at San Francisco. - Flasks	59,926	1,797,780	32,078	979,189	22,926	1,203,615	22,993	1,245,689	30,164	1,108,527
Nickel - val. at Phila. - lbs.	329,968	164,984	277,904	179,975	233,488	134,093	92,252	50,739	49,399	22,197
Aluminum - val. at Pittsburg - lbs.	—	—	283	2,550	61,281	61,281	259,885	172,824	339,629	266,903
Tin - lbs.	—	—	—	—	—	—	162,000	32,400	8,938	1,788
Antimony {value at San Francisco - short tons	50	10000	50	10,000	129	40,756		56,466	250	45,000
Platinum (crude) Troy oz. value at San Francisco	100	400	250	187	600	2,500	80	550	75	517
Total value of metals -		$ 190,038,865		$ 181,586,587		$ 305,785,670		$ 307,716,239		$ 249,981,866
Non-metals - Spot values. —										
Bituminous Coal - - - long tons	38,242,641	$ 53,443,718	64,840,668	$ 82,347,648	99,392,871	$ 110,420,801	113,264,792	$ 125,124,381	114,629,671	$ 122,751,618
Pennsylvania Anthracite " "	25,580,189	42,196,628	34,225,548	76,671,948	41,489,858	66,383,772	46,850,450	82,402,000	48,185,306	85,687,078
Building Stones.	—	18,356,055	—	19,000,000	—	47,000,000	—	48,706,625	—	33,865,573
Petroleum - - bbls.	26,286,123	24,183,233	21,847,205	19,198,243	45,822,672	35,365,105	50,509,136	26,034,196	48,412,666	28,932,326
Lime - - - - bbls.	28,000,000	9,000,000	40,000,000	20,000,000	60,000,000	35,000,000	65,000,000	40,000,000	58,000,000	35,960,000
Natural Gas.	—	—	—	4,857,200	—	18,742,725	—	14,800,714	—	14,346,250
Cement. bbls.	2,072,943	1,852,707	4150,000	3,492,500	8,000,000	6,000,000	8,758,621	7,152,750	8,002,467	6,262,841
Salt. bbls.	5,961,060	4,829,566	7,038,653	4,525,345	8,776,991	4,252,286	11,698,890	5,654,915	11,816,172	4,054,668
Phosphate Rock. long tons.	211,377	1123,823	437,856	2,846,064	510,499	3,213,795	681,571	3,296,227	941,363	4,136,070
Limestone for Iron Flux. long tons.	4,500,000	3,800,000	3,356,936	1,676,478	5,521,622	2,760,811	5,172,114	3,620,840	3,958,055	2,374,833
Mineral Waters. gals. sold	2,000,000	500,000	9,148,431	1,312,845	13,907,418	2,600,750	21,876,604	4,905,970	23,544,495	4,246,734
Zinc white. short tons.	10,107	763,738	15,000	1,050,000	—	1,600,000	21,500	2,200,000	24,059	1,804,420
Others not specified here.	—	9,229,617		11,531,822		13,331,909		—(?)		—(?)
Grand Total Value of Mineral Products		$ 369,319,000		$ 429,398,680		$ 654,506,161		$ 688,616,869		$ 609,821,670

Production of different varieties of Iron Ore in U.S., 1893.
(from "Mineral Resources of U.S." 1893, by D.T. Day.)

States and Territories	Principal Districts or Mines.	Red Hematite.	Brown Hematite.	Magnetite.	Carbonate.	Total.
		long tons.	long tons.	long tons.	long tons.	long tons.
Michigan.	Gogebic Range Marquette " Menominee "	4,636,128	23,420	8,776	—	4,668,324
Alabama.	Sehkooda, Fossil, Ware, Muscada, Mines	1,281,292	461,118	—	—	1,742,410
Minnesota.	Vermilion Range Mesabi "	1,499,927	—	—	—	1,499,927
Pennsylvania.	Cornwall Ore Hills	57,633	158,376	480,164	1,812	697,985
Virginia and W. Virginia		41,665	568,800	6,500	—	616,965
New York.	Lake Champlain District.	15,890	35,592	440,693	41,947	534,122
Wisconsin.	Gogebic Range Menominee "	434,629	4,800	—	—	439,429
Tennessee.		185,365	181,411	—	6220	372,996
New Jersey,		2,348	2,349	351,453	—	356,150
Georgia and North Carolina.		38,012	138,221	9,782	—	186,015
Colorado.		4,654	139,117	27,179	720	171,670
Missouri.	Iron Mountain	68,263	9,600	—	—	77,863
Ohio.		—	—	—	68,141	68,141
Connecticut & Massachusetts	Salisbury District	—	49,752	—	—	40,752
Kentucky.		2,231	30,244	—	4,239	36,714
Texas.		—	22,620	3,000	—	25,620
Maryland		—	2,075	—	11,755	13,830
Idaho, Montana New Mexico, Oregon, and Utah		4600	30,777	3,339	—	38,716
Total		8,272,637	1,849,272	1,330,886	134,834	11,587,629

Note.

Average value of iron ore for United States as a whole, was, in 1893 $1.66 per ton at the mine. Highest value reported in Conn. & Mass. $3.01 per ton; lowest value was in Alabama, $0.86 per ton.

Quantity and Value of Iron Ores Imported to United States in 1892 and 1893. (Mineral Resources-1893-Day.)

Country.	Districts, or Mines.	1892		1893.	
		Quantity	Value	Quantity	Value.
Spain.	From the northern and southern provinces	Long tons. 236,957	$483,847	Long tons. 99,640	$187,263
Cuba.	Juragua Mines S.E. part of island	307,115	$618,222	349,977	$488,156
French Africa and Oceanica.	Mostly from Algeria and New Caledonia	62,502	$126,238	16,541	$33,357
Italy.	Magnetite, "Elba ore," Isle of Elba	95,313	$321,988	16,371	$46,457
England.	Mostly from the Hodbarrow Mine	35,638	$76,910	16,798	$54,610
Greece.	Mostly from islands of Seriphos (& Cypriano)	44,602	$69,044	10,244	$17,324
British Columbia.	From Texada Island	2,749	$10,141	469	$1,441
Portugal.	Northern part.	6,490	$14,386	10,552	$23,589
Quebec, Ontario, Manitoba and Northwest Territory.	Nearly all from near City of Ottawa	8,606	$17,199	372	$990
Turkey in Europe.	Western part	3,346	$32,818	1,029	$10,803
Turkey in Asia.	Western part	———	———	4,700	$40,576
Other Countries.		3,267	$24,851.	258	$2,121
Total.		806,585	$1,795,644	526,951	$906,687

Note.

The values given represent the selling price at port of shipment, to which must be added the cost of ocean carriage, import duty of 75 cents per ton, dock charges, etc. The duty since Aug. '94 has been 40 cents per ton.

The high value of the Turkish ores is due to the chromic oxide contents.

Nearly all the foreign iron ores are used in the works at Sparrows Point, Md.; Steelton, Pa., and Bethlehem, Pa..

Minerals of Interest to Iron Smelters.

Iron Ores, Proper.

Magnetite -	Fe_3O_4 ---	72.4% Fe.	
Hematite -	Fe_2O_3 ---	70.0%	" Sometimes called "Hard ore".
Limonite -	$2Fe_2O_3 \cdot 3H_2O$ --	59.92%	" Commonly called Brown Hematite
Goethite -	$Fe_2O_3 \cdot H_2O$ --	62.93%	" Occurs associated with Limonite.
Turgite -	$2Fe_2O_3 \cdot H_2O$ --	66.29%	" " " " "
Siderite -	$FeO \cdot CO_2$ --	48.3 %	" Although low grade, it is very important.

Minerals which, after the extraction of one of their elements, become Ores of Iron.

Pyrite ----- FeS_2 --- 46.7% Fe. - Used for making sulphuric acid.

Franklinite - $(FeO \cdot MnO \cdot ZnO)(Fe_2O_3 \cdot Mn_2O_3)$ about 46% Fe. — Used for making Zinc-white and spiegeleisen.

Minerals used in making special kinds of Steel.

Chromite. - $FeO \cdot Cr_2O_3$ -- - used in making Chrome Steel.

Wulframite - $(FeO \cdot MnO)WO_3$ - used in making Tungsten Steel.

Pyrolusite - MnO_2 --- used in making Manganese Steel.

Minerals which are harmful in Iron Smelting.

Menacconite. - Fe_2O_3 & TiO_2 - Forms obstructions in the Furnace ("salamander")

Pyrite. ----- FeS_2 --- Harmful on account of its Sulphur

Pyrrhotite. --- Fe_7S_8 " " " " " "

Gypsum. --- $CaSO_4 \cdot 2H_2O$ " " " " " "

Barite. ---- $BaSO_4$ " " " " " "

Chalcopyrite. -- $CuS \cdot Fe_2S_3$ " " " " " " and Copper

Arsenopyrite. - $FeSAs$. " " " " " " " Arsenic.

Vivianite. --- $3FeO \cdot P_2O_5 \cdot 8H_2O$ " " " " " Phosphorus.

Apatite. ---- $Ca_3P_2O_4 + CaCl_2$ (or $CaCl_2$) " " " " "

Also any other mineral containing S, P, As, Ti, etc.

The Blast Furnace Process for the Manufacture of Pig Iron.

The process consists of two steps Roasting and Smelting. The roasting is left out except in a few cases where it is needed.

Roasting the ore. This is done either in a heap or in a kiln, using wood, coal, or gas for fuel, and has for its object the removal of sulphur, carbonic acid, and water, and also to increase the porosity of the ore. By the removal of water and carbonic acid, the fuel consumption of the blast furnace is lessened. In the removal of Sulphur from pyrite, the FeS_2 by heat alone yields Fe_8S_9 and S. With free admission of air, it yields Fe_2O_3, $FeSO_4$, and SO_2. At higher heat $FeSO_4$ is decomposed into FeO and SO_3.

The increase of porosity renders the ore permeable to the reducing gases and, therefore, much easier to reduce in the furnace.

Roasting in heaps is slow and requires high fuel cost. It is now seldom used.

Kilns are of two classes, those using solid fuel and those using gaseous fuel.

The Gjers Kiln, figure 1, is an example of the first class. The ore and coal are fed together at the top, and the roasted ore is drawn at the bottom. Air enters at the holes around the side, a, a, a, and also under the cone in centre at b, b. In A. I. M. E., Vol. XII, p. 372, the fuel consumption is given as 50 to 100 lbs. of coal per ton of ore, and the cost as 30 cents per ton. This kiln roasts from 10 to 50 tons per day.

Gjers Kiln.

PLAN.

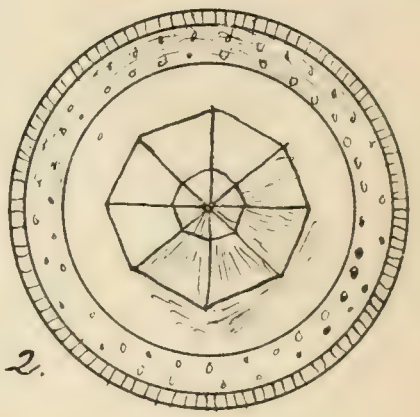


fig. 2.

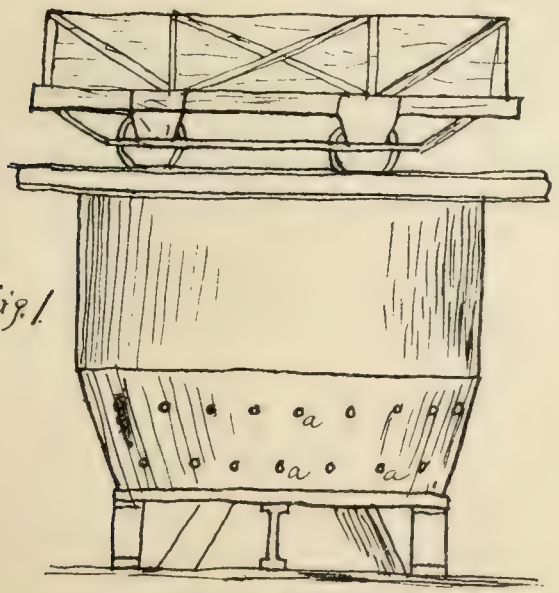


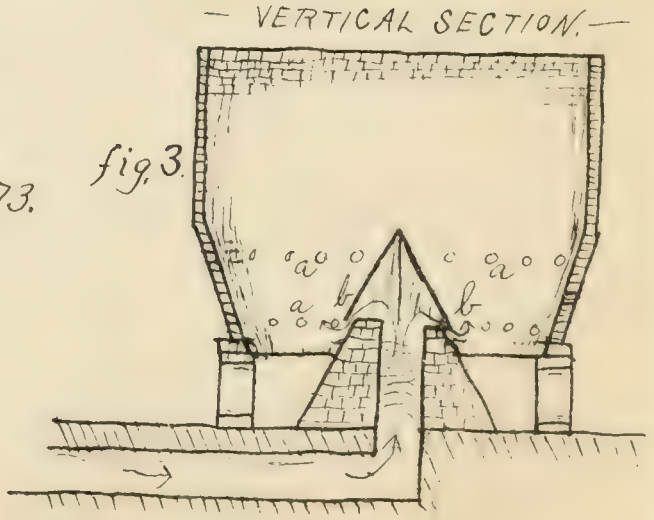
fig. 1

ELEVATION.

A. I. M. E.
Vol. XII, p. 373.

— VERTICAL SECTION. —

fig. 3.



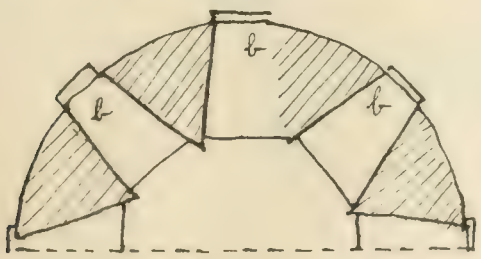
The following figures, taken from A.I.M.E. vol. XVIII, p. 309, show what the kiln does. Ore from Cornwall, Pa., which contained 2.5% to 3.5% of sulphur, gave when roasted in the Gjers kiln! ——

Per cent Total sulphur	Per cent of Sulphur as sulphate.	Per cent of Sulphur as sulphide.	Per cent of total sulphur as sulphate.
1.333	0.283	0.850	24.977
1.380	0.135	1.245	9.782
1.873*	0.096	1.777	5.125

* Clinkered.

Westman Kiln.

The second class includes the Westman kiln, figure (4 etc.) which is used very extensively in Sweden. Ore is charged at the top. Gas enters at a. Air is admitted at a & b. The roasted ore is withdrawn at b, b. The principal fault of this furnace seems to be the presence of a central cone of ore to which the air never penetrates. e is the gas pipe. f, f, f are working holes. Air is sometimes admitted through the lower working holes. Each gas jet is regulated by a valve.

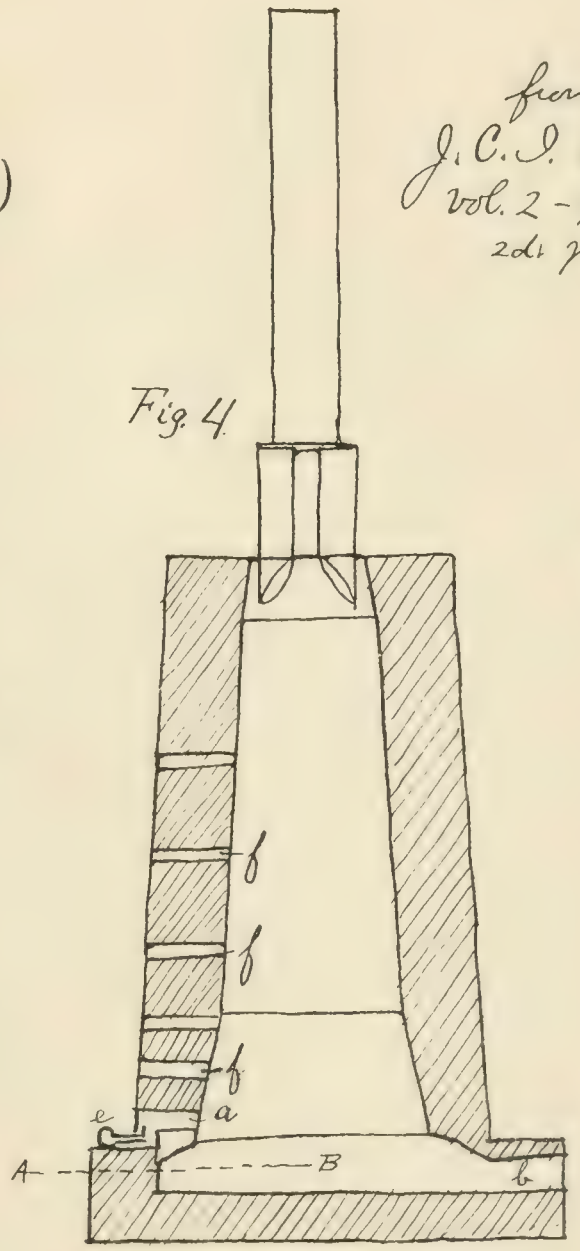


Half Section on A.B.

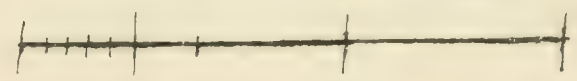
Fig. 6

from
J.C.I.W.
vol. 2 - p. 208
2d plate.

Fig. 4

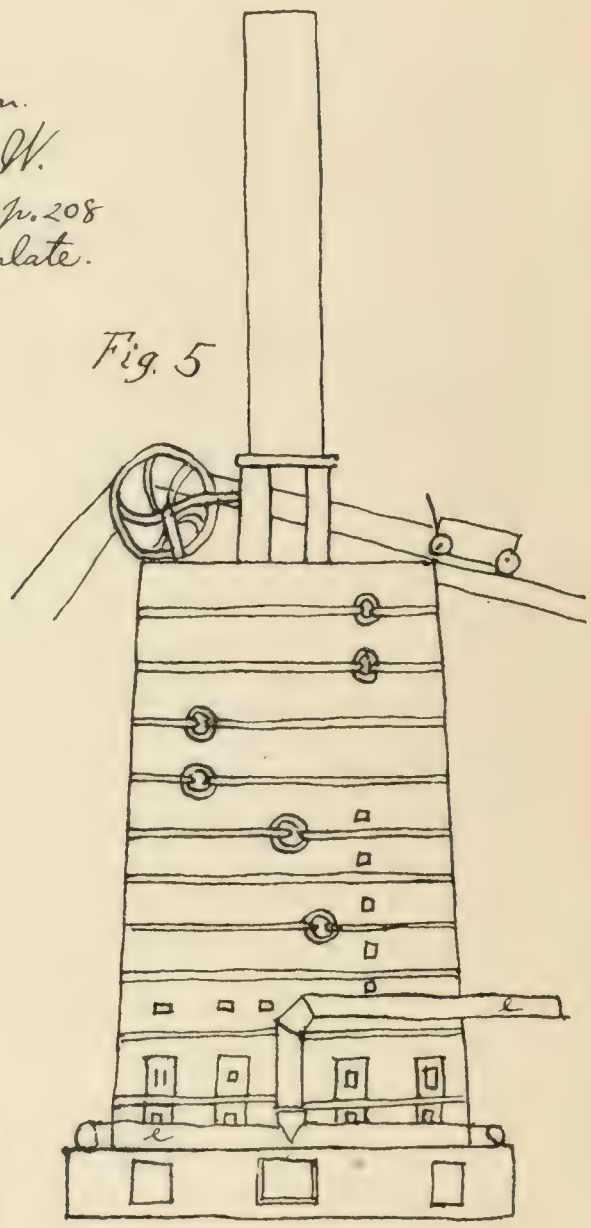


VERTICAL SECTION.



SCALE.

Fig. 5



ELEVATION.

Heap Roasting.

(Notes of Summer School 1878 - R.H.R.)

The following method of heap roasting has been used at Steelton, Pa., with good results. Ore and fine coal were made into heaps according to the following sketches:-

Fig. 7.

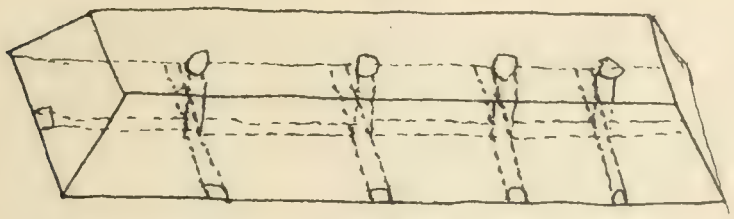


Fig. 8.

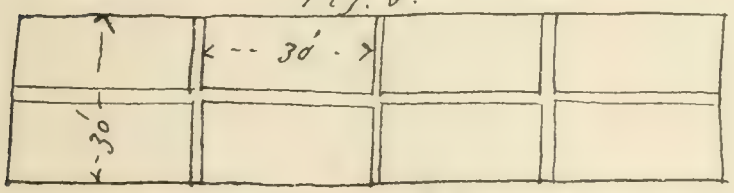
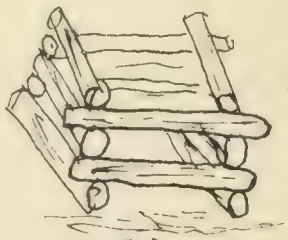


Fig. 9.



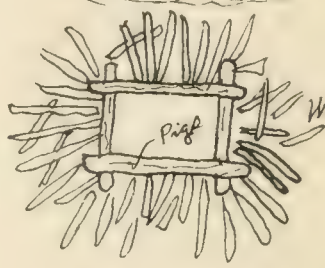


Fig. 10.

Fireplaces about 15" square inside and about 18" high are built at the bottom of the central flues, by piling up pigs of iron, corn-cob fashion. (see figs. 9 & 10). Around these fire-places is laid some wood for kindling. Above the pigs the flues are about 10" square and are formed by leaving in pieces of joist which are not pulled out till the heap is completed. The little longitudinal and lateral flues are made with lumps of ore

The lateral flues are 30' apart.

The ore is laid in 18" layers. A single layer of wood is put under the whole heap, then a layer of fine coal is put on that and between the layers of ore. The coal needed is generally 10% of the ore, sometimes up to 15% of the ore. The heap is made 8 to 10 feet deep.

The ore is roasted from 4 to 8 weeks, the longer, the better. Ore should not be roasted too fast.

The heap is lighted in the central flues, and the fire spreads through the whole heap by means of the smaller flues. The heap is covered with ashes, and the rate of roasting is regulated by the ashes which are pushed in and out from the side flues, or by the holes which may be pricked in the top.

If the fire is too hot the ore melts; if too cold it doesn't roast. Outer layer of heap never roasts; but has to be put on the next heap. The longer a heap can be exposed to the weather to wash out the $FeSO_4$, the better. Sometimes the heap is washed down with hose to get out the $FeSO_4$.

The Davis-Colby Kiln, figure is one of the latest types of the second class.

Raw ore is charged at T. Gas enters at X. Air enters through the chutes, C, C, ; firedoors, B, B; and poking holes Z, Z. Roasted ore is withdrawn at C, C. The capacity is 70 to 90 tons per day. The results obtained with this kiln are shown by the table of analyses at the bottom of this page.

In Roasting Ore to eliminate sulphur, it should never be sintered before being thoroughly oxidized, as it then becomes impervious to air.

To a certain extent, roasting takes place at the top of a blast furnace. Water and carbonic acid both consume fuel; sulphur is only imperfectly driven off for want of oxygen.

Fig. 11.

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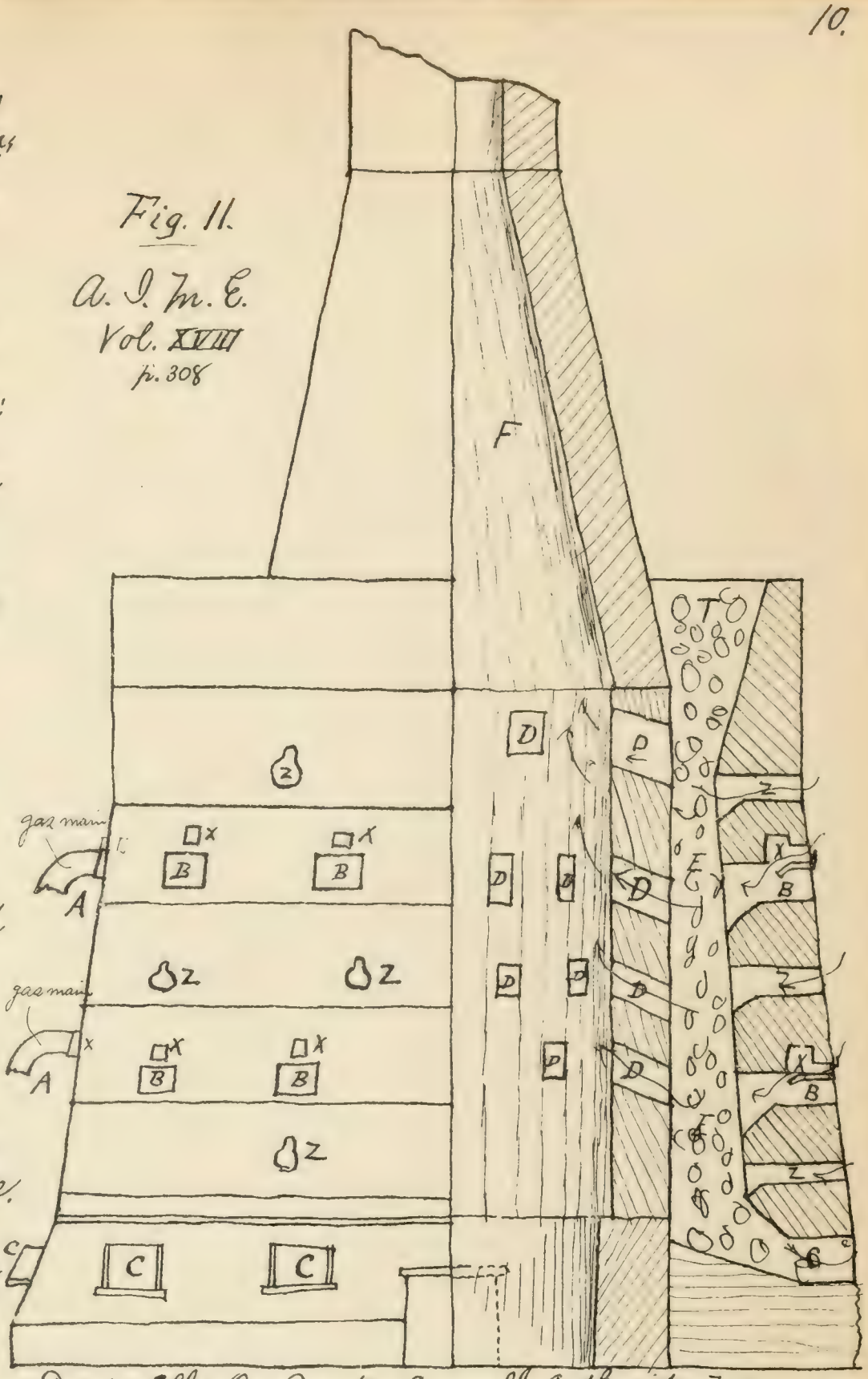


Davis-Colby Ore-Roaster, Cornwall Anthracite Furnaces. Cornwall, Pa.

Ore from Cornwall, Pa., which contained 2.5% to 3.5% of sulphur, gave when roasted in the Davis-Colby kiln -

Per cent Total Sulphur.	Per cent Sulphur as Sulphate.	Per cent Sulphur as Sulphide	Per cent of total Sulphur as Sulphate.
0.666*	0.133	0.533	19.96
0.602*	0.105	0.497	17.44
0.782	0.424	0.358	54.21
0.798	0.318	0.480	39.85
0.596	0.281	0.315	49.14
0.740	0.206	0.534	27.83

*clinkered.

Table from A. I. M. E. Vol. XVIII, p. 310.

List of Blast Furnaces in United States

Jan. 1894.

(From "Mineral Resources" 1893 - Day.)

States.	anthracite	Bituminous & Coke.	Charcoal.	Total.
Massachusetts.	—	—	4	4
Connecticut.	—	—	7	7
New York.	19	2	6	27
New Jersey.	14	—	—	14
Pennsylvania.	109	76	14	199
Maryland.	—	5	6	11
Virginia.	—	24	8	32
West Virginia.	—	4	—	4
Kentucky.	—	6	3	9
Tennessee.	—	13	9	22
North Carolina.	—	2	—	2
Georgia.	—	2	3	5
Alabama.	—	38	14	52
Texas.	—	1	4	4
Ohio.	—	55	10	65
Indiana.	—	2	—	2
Illinois.	—	19	—	19
Michigan.	—	—	20	20
Wisconsin.	—	4	6	10
Minnesota.	—	1	—	1
Missouri.	—	3	2	5
Colorado	—	3	—	3
Oregon.	—	—	1	1
Washington.	—	—	1	1
Total.	142	259	118	519

Condition of Blast Furnaces in the United States for year ending Dec. 31, '93.

(From "The Mineral Industry" - 1893 - p. 350)

Total No. of Furnaces in U.S.				518
Anthracite.	Total.			141
	Out of blast.			107
	In blast.			34
Bituminous and Coke.	Total.			259
	Out of blast.			175
	In blast.			84
Charcoal.	Total.			118
	Out of blast.			99
	In blast.			19
Total.	Out of blast.			381
	In blast.			137

Average output per Furnace (per yr.) (Tons of 2240 lbs.)

By Fuel used.	Anthracite.	39633
	Bituminous and Coke.	64,168
	Charcoal.	20,357
By No. in blast.		52,003

Smelting.

This subject will be treated under the following heads:-

1. The Blast Furnace Plant.
2. Materials for Smelting.
3. Management of the Blast Furnace.
4. Chemistry and Heat " " " "
5. Regulating " " "
6. Pig Iron Classified.
7. Properties of Pig Iron.
8. Uses of Pig Iron.

1. The Blast Furnace Plant.

The location is usually chosen according to the cost of assembling the materials needed in smelting, (ore, coke, coal, limestone, and fire-brick) and of getting the product to market. Further than this, the works should have enough level space for buildings, yards, etc.; a ready means for disposing of slag; and a good water supply. The old idea of placing a blast furnace on a hillside is now wholly supplanted by the use of an elevator.

The Blast Furnace Plant, figures 12 & 13, consists of:- Blast Furnace, Boilers, Blowing Engines, Stoves, Pumps, Stock House, Scales, Elevator and Filling Arrangement, Casting House, Pig Yard, Slag Dump, Stock Tracks, Slag Tracks, Pig Tracks.

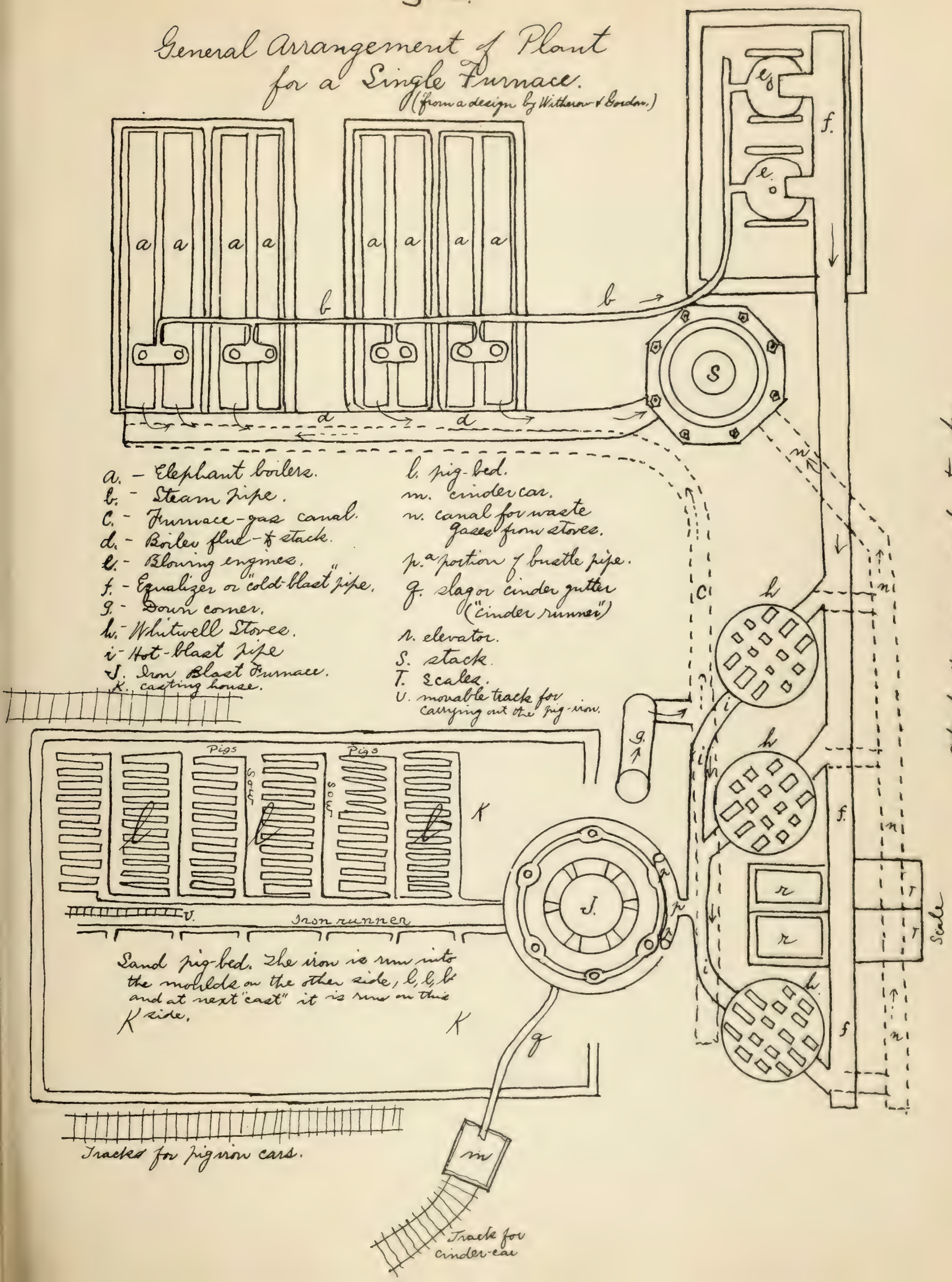
The Blast Furnace.

The blast furnace, figure 14, is a brick structure usually circular in section. The furnace is built in two sections, The upper part rests on the columns, 4, 4, while the lower portion rests directly on the foundations. The upper portion may be sheathed with boiler plates, figure , or it may be of naked fire-brick bound with iron hoops, figure . The crucible of the furnace (See Fig. 14.) being subjected to the most intense heat is generally water cooled. Some of the coolers used are shown in figures 17, 18, and 19. Figure 17 consists of a series of flew circular gutters. Water is run into the upper gutter and overflows into those beneath.

Fig. 12.

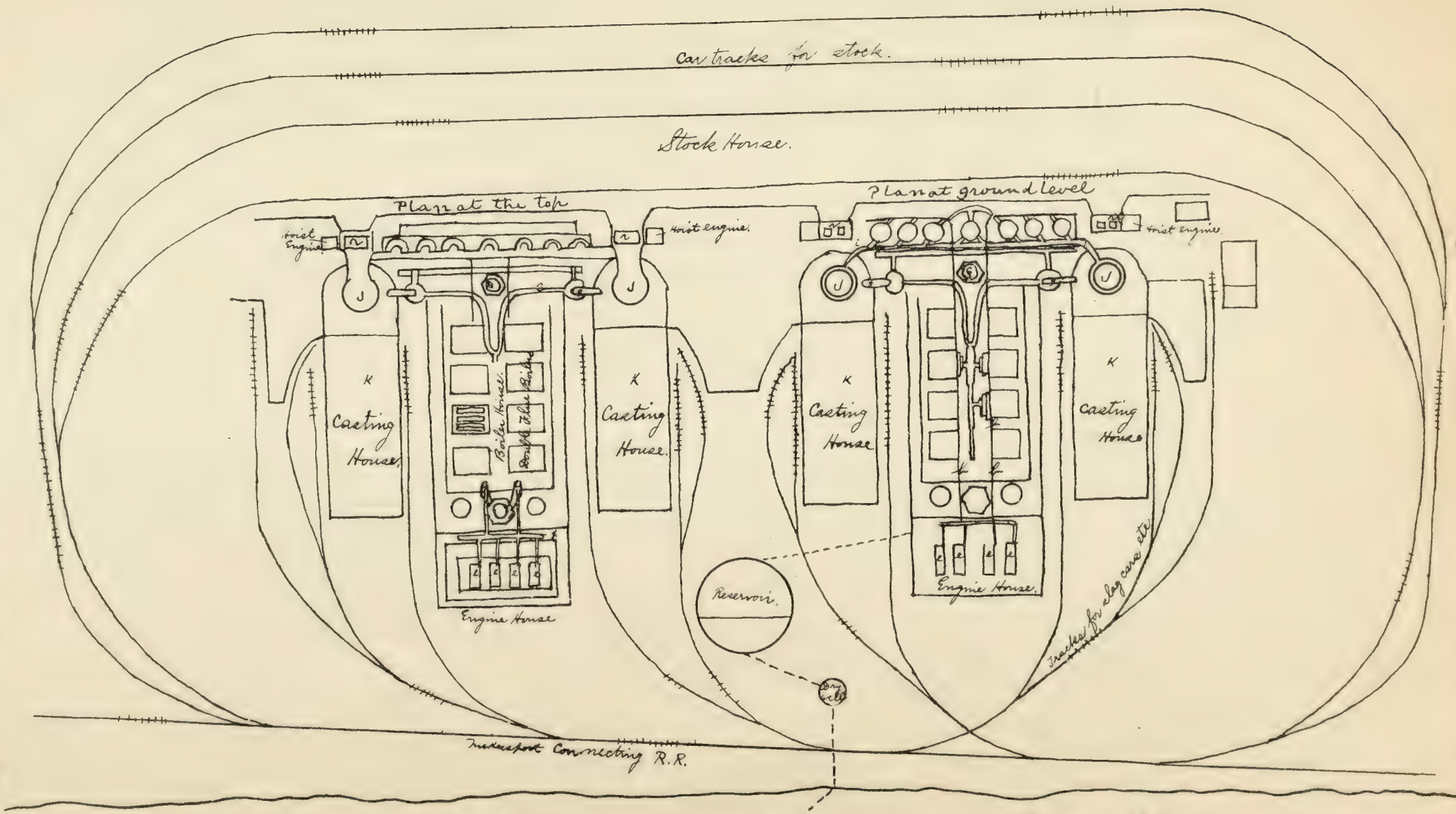
General Arrangement of Plant for a Single Furnace.

(From a design by Witherow & Gordon.)



a. – Elephant boilers.
b. – Steam pipe.
C. – Furnace-gas canal.
d. – Boiler flue – to stack.
e. – Blowing engines.
f. – Equalizer or "cold-blast" pipe.
g. – Down comer.
h. – Whitwell Stoves.
i – Hot-blast pipe
J. Iron Blast Furnace.
K. casting house.
l. pig-bed.
m. cinder car.
n. canal for waste gases from stoves.
p. a portion of bustle pipe.
q. slag or cinder gutter ("cinder runner")
r. elevator.
S. stack.
T. scales.
V. movable track for carrying out the pig-iron.

General arrangement of Furnace Plant for 4 Furnaces.



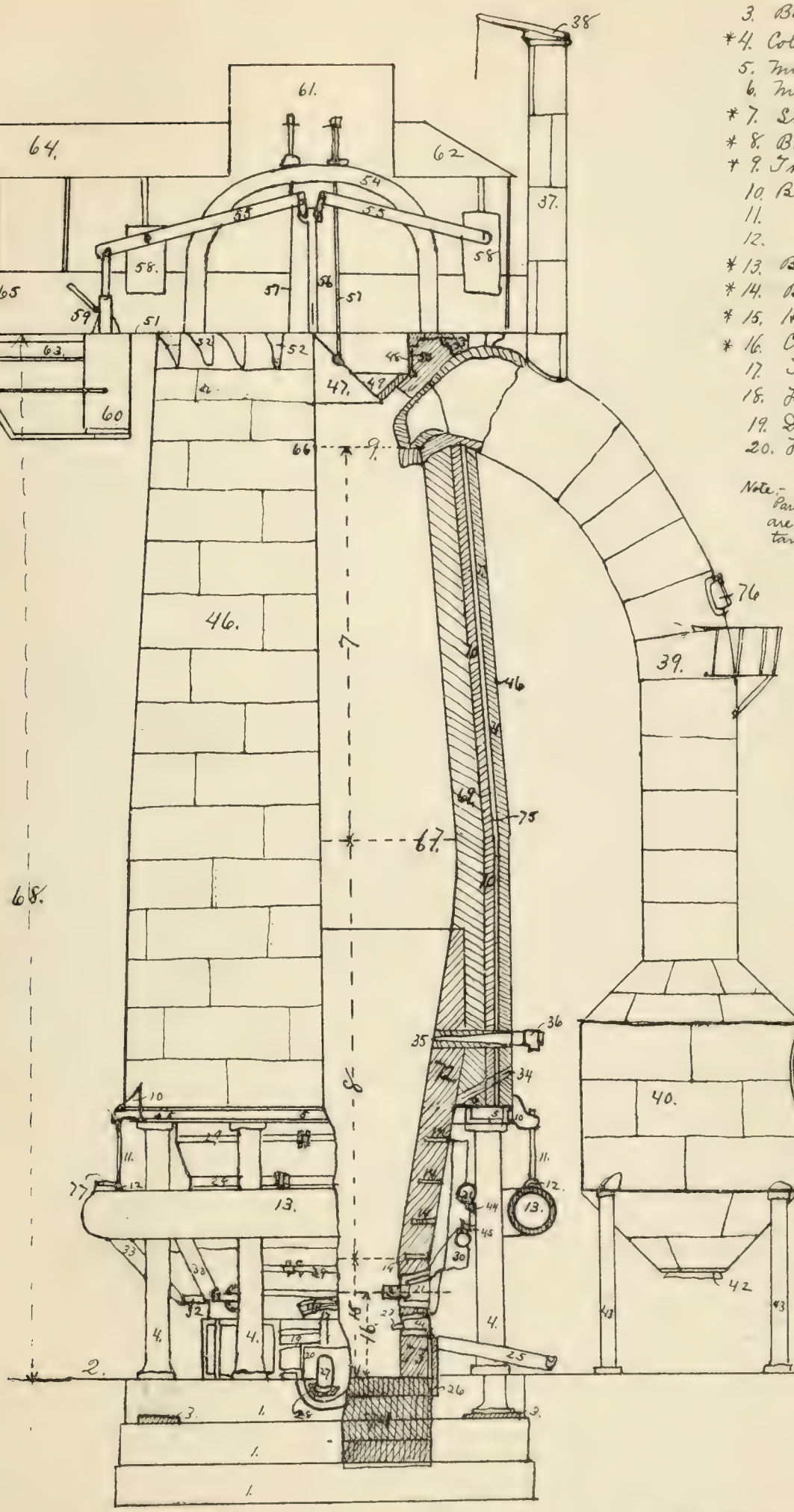
Plan of Monongahela Furnace Co.'s Plant (4 furnaces completed.)
McKeesport, Pa.
(from Iron Age, aug. 7-'90)

Fig. 13.

Note. The small letters have the same meanings as in the last on page 13.

The Blast Furnace.

Fig. 14.



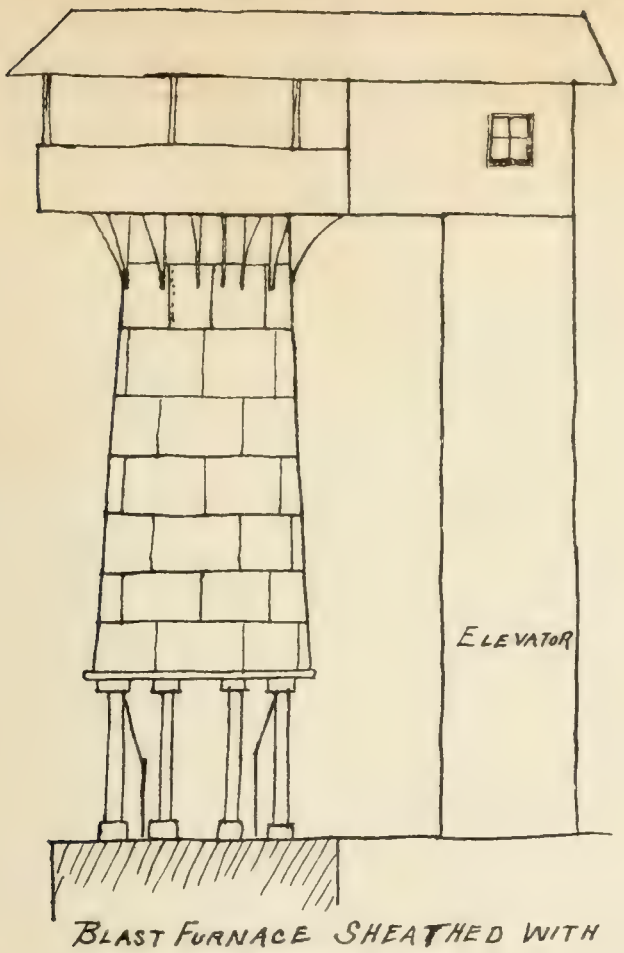
* 1. Foundation.
* 2. Hearth-level.
3. Base-plates.
* 4. Columns.
5. Mantel-beams.
6. Mantel-plate.
* 7. Shaft.
* 8. Boshes.
* 9. Throat.
10. Bustle-pipe bracket.
11. " " hanger.
12. " " saddle.
* 13. Bustle pipe.
* 14. Bosh-plates.
* 15. Hearth.
* 16. Crucible.
17. Tymp.
18. Front or tymp-arch.
19. Dam.
20. False or monkey-dam.

Note.- Parts marked with * are the most important.

* 21. Tuyere.
* 22. Nozzle.
* 23. Slag or Cinder-notch.
* 24. Slag or Cinder-notch arch.
* 25. Slag or Cinder-runner.
* 26. Hearth jacket.
* 27. Tap Hole.
* 28. Iron runner.
29. Grinding Bands.
30. Waste-water Pipe.
31. Feed-water pipe.
* 32. Belly-pipe.
* 33. Tuyere-stock.
34. Ventilating Ports.
35. Bosh ports.
* 36. Bosh-tuyere.
* 37. Bleeder.
* 38. Bleeder valve.
* 39. Down-comer.
* 40. Dust-catcher.
* 41. Dust-catcher Goose-neck.
* 42. Dust-catcher bell.
43. " " columns.
44. Feed-water-Pipe Bracket.
45. Waste-water-pipe Hanger.
* 46. Furnace-shell.
* 47. Bell.
* 48. Hopper.
49. Hopper extension ring.
50. Hopper lip-ring.
* 51. Top platform.
52. Platform brackets.
53. Hopper-brackets.
* 54. Bell arch.
* 55. Bell beams.
56. Bell lifting-rod.
57. Bell safety-rods.
58. Bell counterweights.
59. Bell-winch.
60. Bell air-cylinder.
61. Waste gas flume.
62. Furnace canopy.
63. Bridge beams.
64. Bridge-roof.
65. Platform-guards.
* 66. Throat or stock-line.
* 67. Bosh.
* 68. Height.
* 69. In-walls.
* 70. In-walls backing.
* 71. In-walls filling.
* 72. Bosh-walls.
* 73. Crucible walls.
* 74. Hearth-blocks.
75. Expansion-space.
76. Explosion-door.
77. Bustle-pipe man-holes.

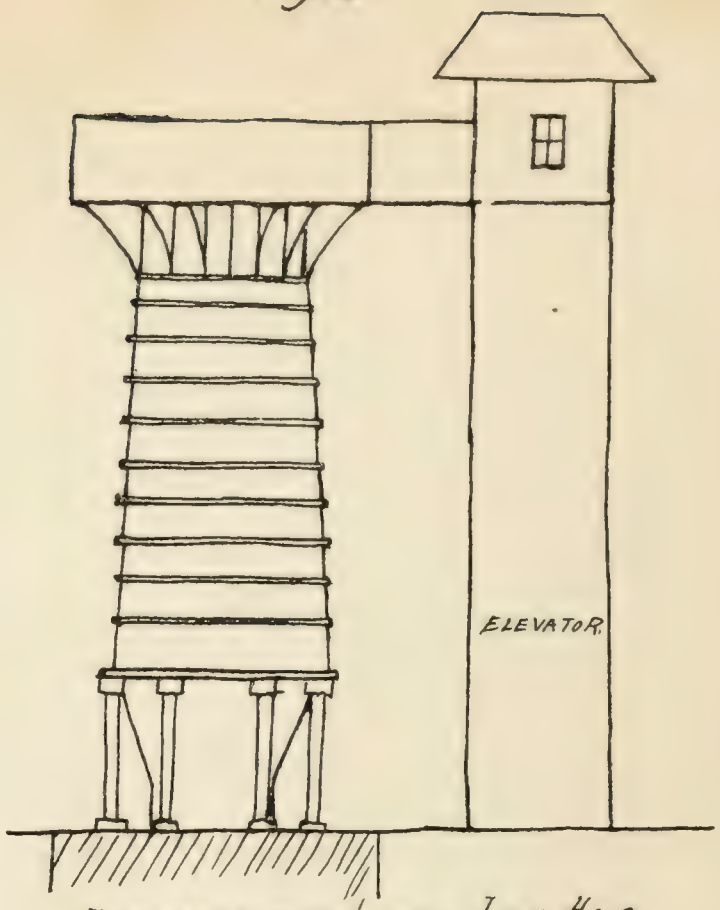
(from A. I. M. E. vol. XVI, p. 333 – 1888.)

Fig. 15.



BLAST FURNACE SHEATHED WITH BOILER PLATES.

Fig. 16.



FIRE-BRICK BOUND WITH IRON HOOPS.

(Continued from page 12.)

Crucible Cooling.

Figure 18 shows a cast iron crucible jacket cooled by water flowing through a wrought iron pipe which is cast in the jacket. These jackets which encircle the crucible are bound together by strong bolts. This method is much used. Sometimes a small space is left between the fire-brick of the crucible wall and the water-cooled jacket. This space is filled with pebbles sifted to a small and uniform size. Water is made to run down through the pebbles and thus help in the cooling.

Figure 19 shows the crucible encircled by plates of iron, between which and the brickwork is a space filled with broken fire brick. Water is run down through this loose packing.

Fig. 18.

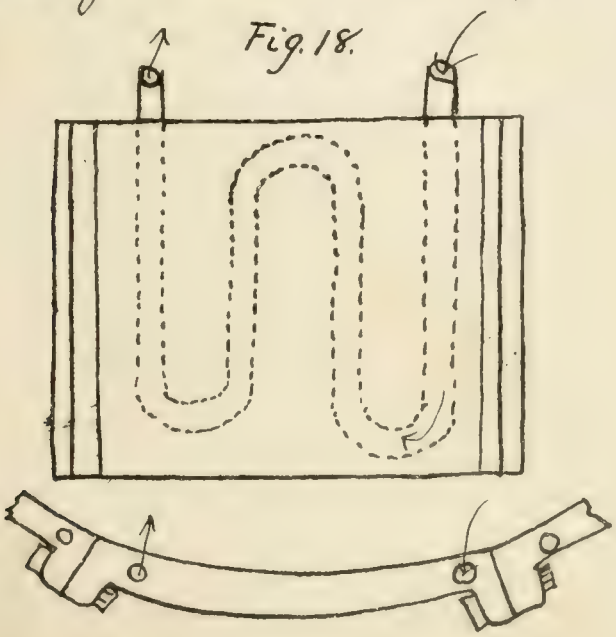


Fig. 17.

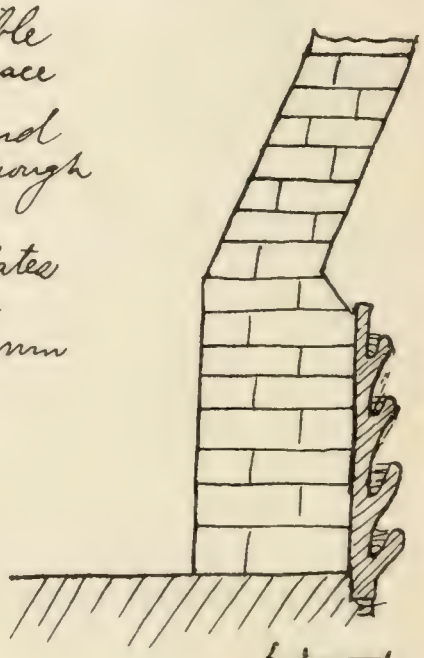
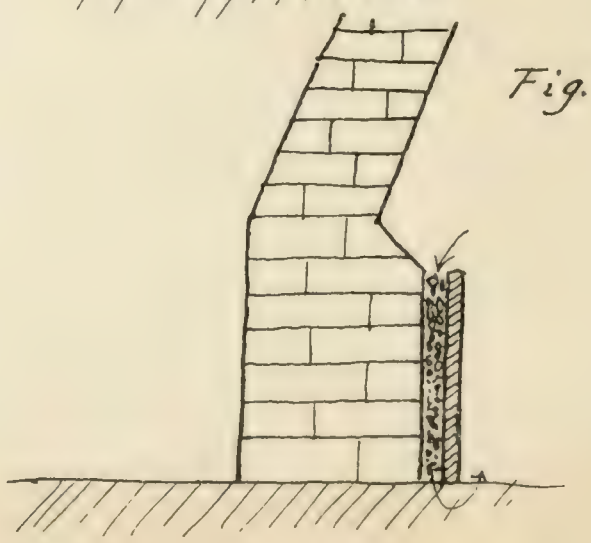


Fig. 19.



Cooling the Boshes.

Fig. 20.

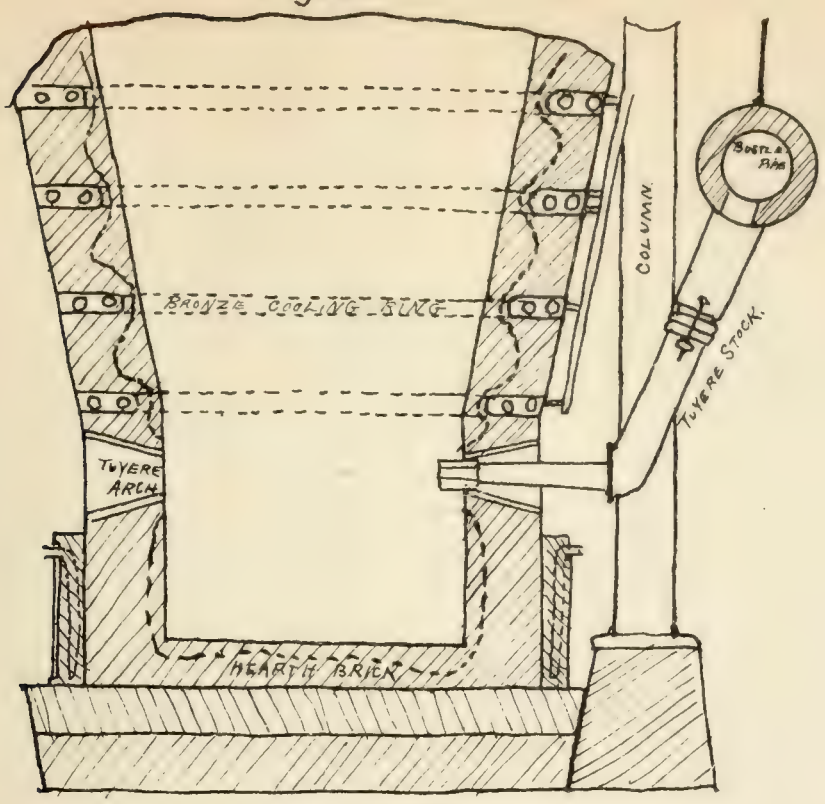


Fig. 21. cold water

Note

Cast-iron water-cooled bosh-jackets similar to the crucible jacket (fig 18) have been used with success by the Maryland Steel Co. By using them a thin bosh-wall (9"-18") is sufficient.

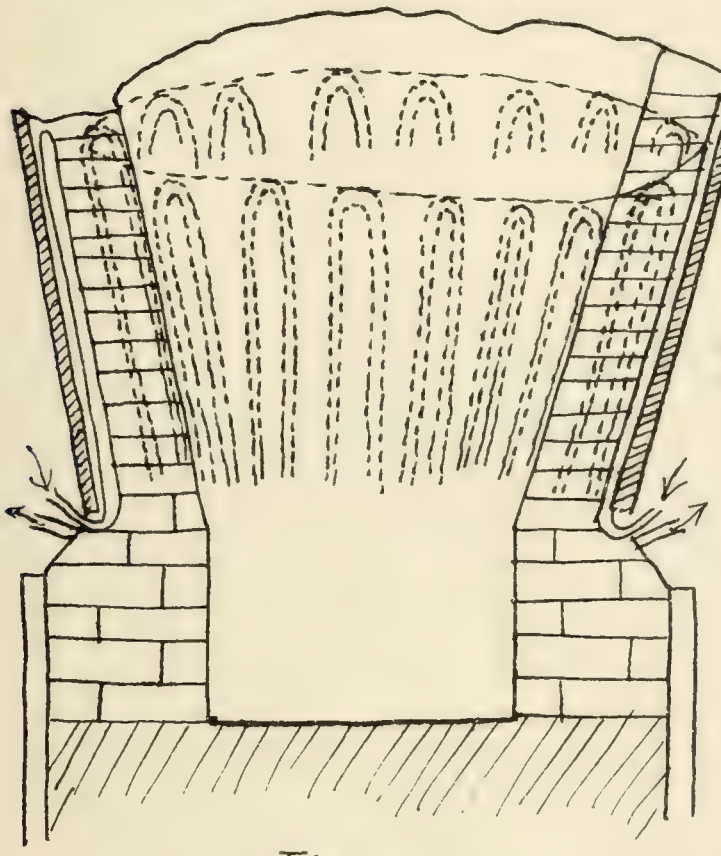


Fig. 22.

Figure 22 shows the use of inverted U pipes for cooling the boshes. They are placed between the sheathing and the brickwork.

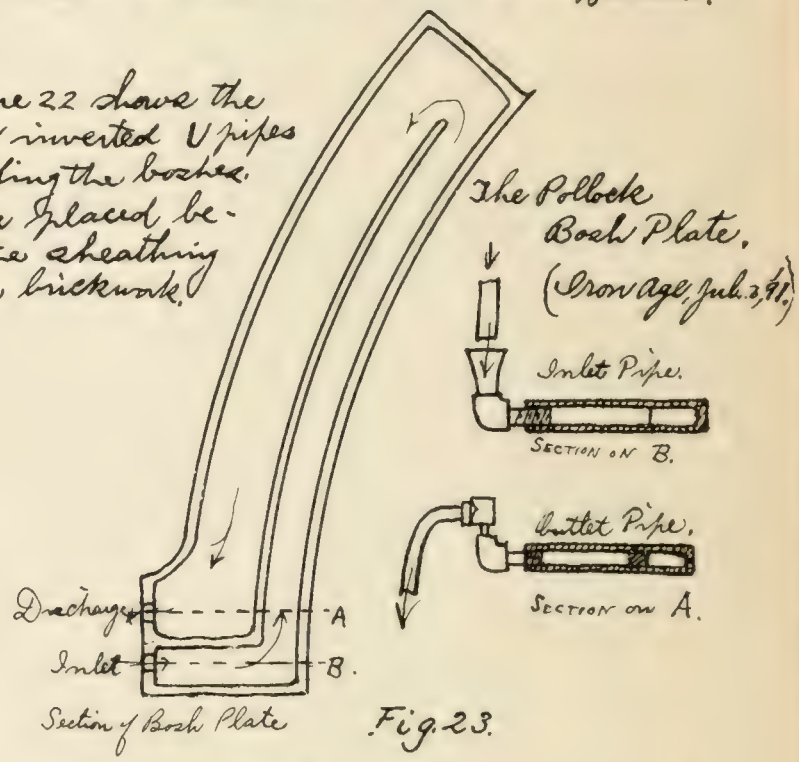


Fig. 23.

The Boshes are kept cool and kept in shape (the "lines" maintained) by means of some arrangement for the circulation of cold water in and around the bosh walls. A primitive method is to have the boshes sheathed with iron plates, and to have water sprayed on the plates.

One of the best methods is to have a series of bronze cooling "rings", "plates" or "blocks", set into the brick-work of the bosh walls. Cold water circulates through pipes or channels which are cast in the bronze. Fig. 21 shows a set of bronze cooling rings (pipes cast in the bronze), and Fig. 20 shows their position in the bosh walls. Fig. 23 shows a type of plate similar to fig. 21, but the water flows through channels instead of pipes. The "feed" and "discharge" of this block makes it easy to detect a leak.

In fig. 20, the heavy dotted line in the bosh wall and around the crucible indicates the appearance of the walls after a furnace has been in blast a long time. The cooling blocks should prevent this as much as possible.

Tapping Hole and Cinder Notch.

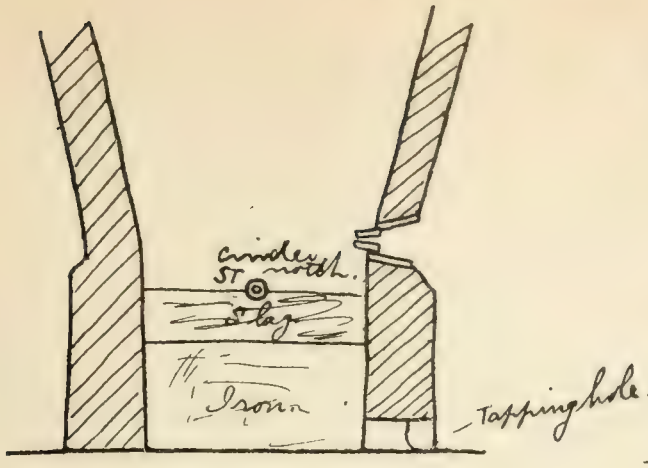


Fig. 24.

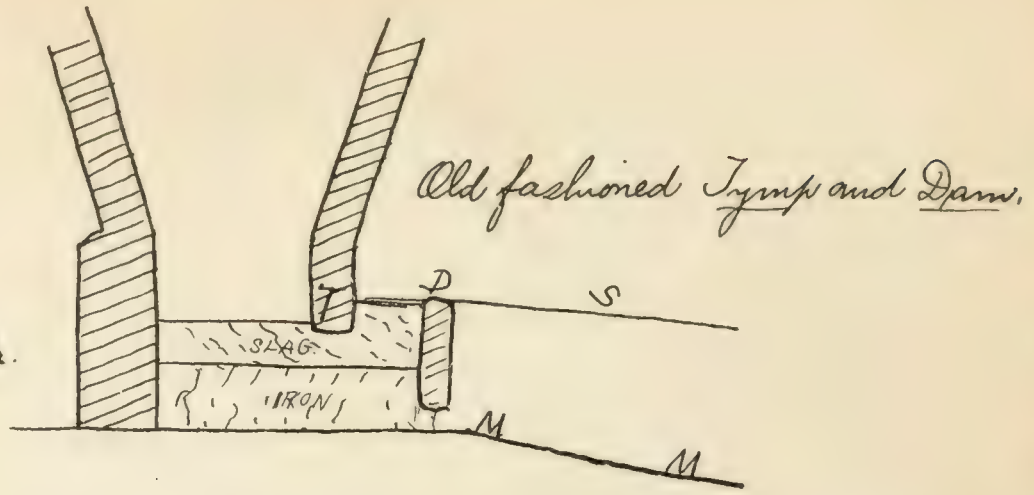
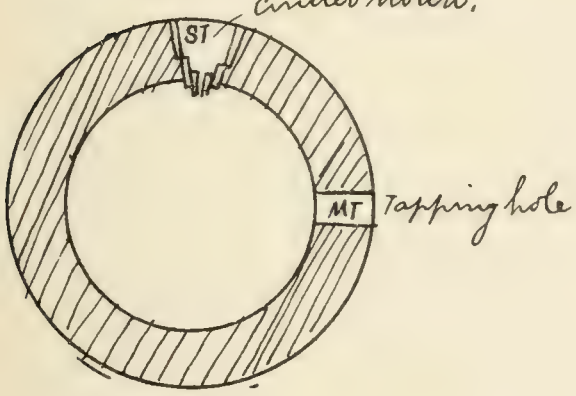
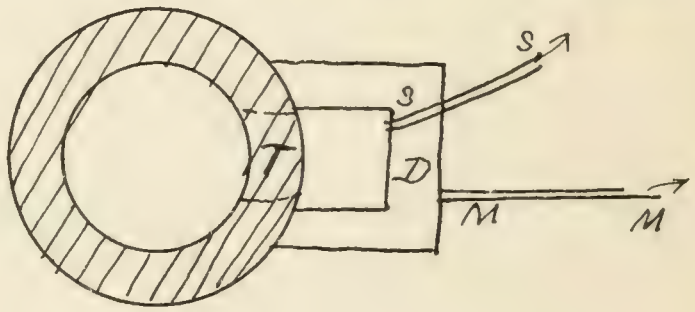


Fig. 25.

T is the tymp or inverted dam.
D is the dam.
SS " " slag tap and runner.
MM " " metal " " "





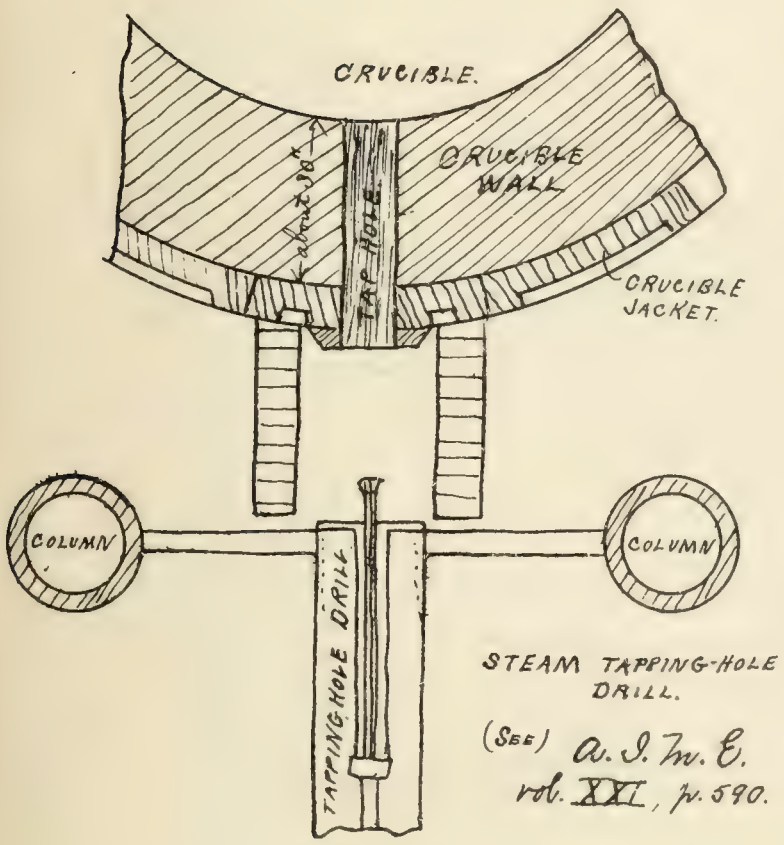


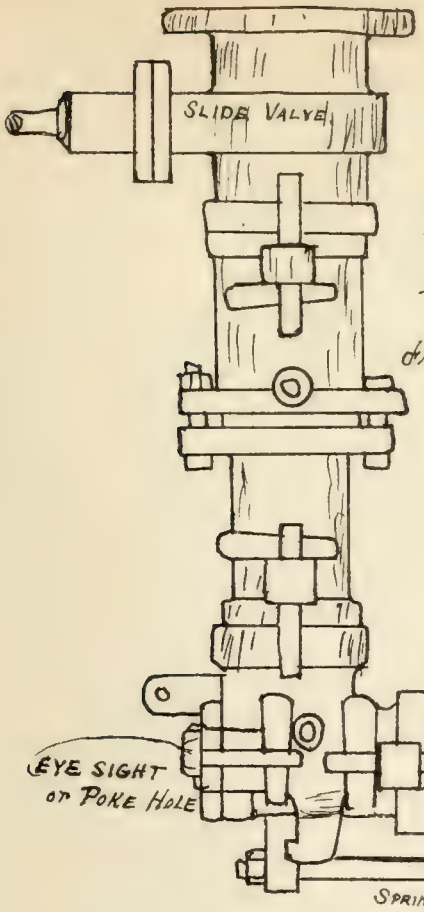
Fig. 26.

There are two methods of tapping off the slag and iron. The older form of "open front." (fig 25). is now little used; this arrangement is called the "tymp and dam."

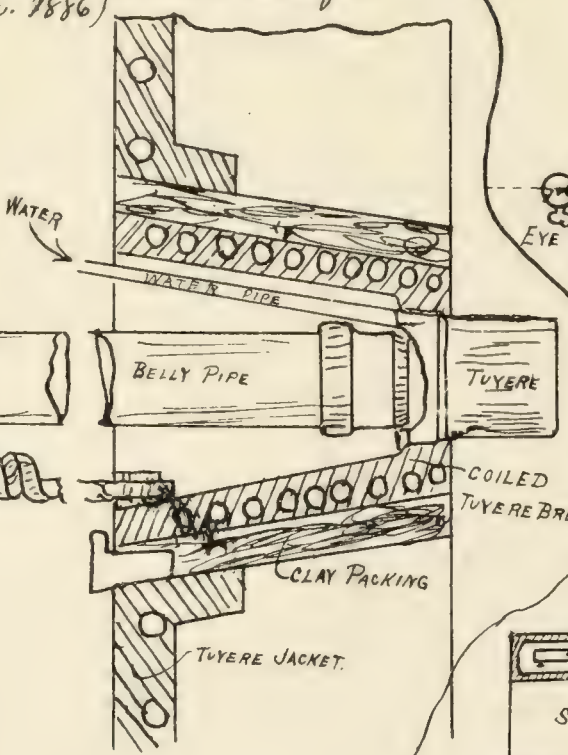
Blast furnaces are now made with "closed fronts" as is shown in figs. 24 and 26. In fig. 24 ST is the "slag-eye" or Lürman cinder notch: the details of it are shown on page 19. MT in fig. 24 is the metal tapping hole where the iron is tapped off. The cinder notch is easily stopped up by an iron plug on a long handle, but the tap hole for the metal has to be plugged with clay in some form. Balls of clay are rammed in after the iron is tapped. This clay is often 2063 feet thick and is soon baked to hard rock. The work of drilling through this hard clay is hard, and requires 8 to 10 men from 10 to 30 minutes to "open" the hole with a long hand-drill.

Fig 26 shows the tap hole of a modern furnace and also a part of a steam tapping hole drill invented by David Baker (M. I. T., '85.) This drill has been used with much success at the furnaces of the Maryland Steel Co., Sparrow's Point, Md. An ordinary steam rock drill fastened to the piston rod of a long steam cylinder is mounted on a frame that can be swung into place in front of the tapping hole. The whole frame and its fastenings, is supported by a crane fastened to the right hand Column. Two men run the drill and open the hole in 3 to 5 minutes.

Fig. 27.



#2
Plain Adjustable Tuyere Pipe for Tuyeres of 4 in. nose or under.
from Jaws and Hartman, catalogue. (Phila. 1886)



Tuyere Stock used by Maryland Steel Co. 1894.

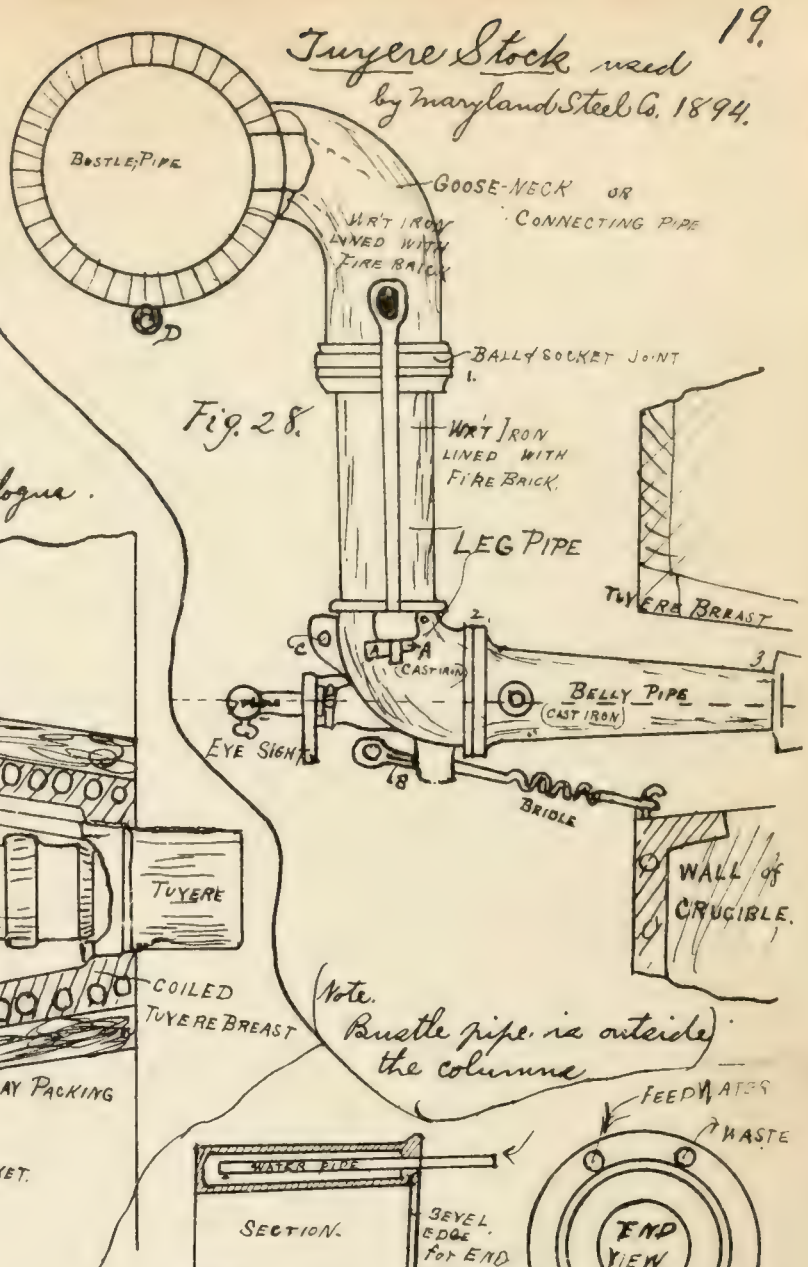
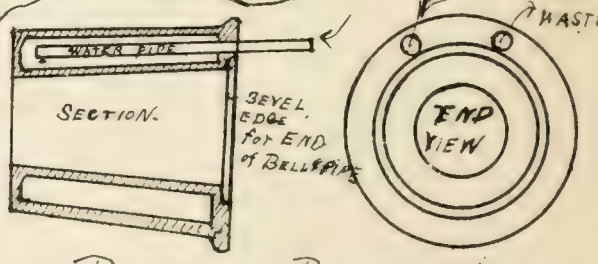


Fig. 28.

Note. Bustle pipe is outside the column



PHOSPHOR BRONZE TUYERE.
Fig. 29.

Tuyere Stocks.

The tuyere stock shown in fig. 28 is very simple and is so put together that the tuyere can be quickly taken out and replaced. The keys 1 and 2 are loosened and the "leg pipe" is pulled back by a tackle fastened to D and C. The belly pipe is held in place by the pressure on its ends caused by the "bridle." There are ball & socket joints at 1, 2, 3.

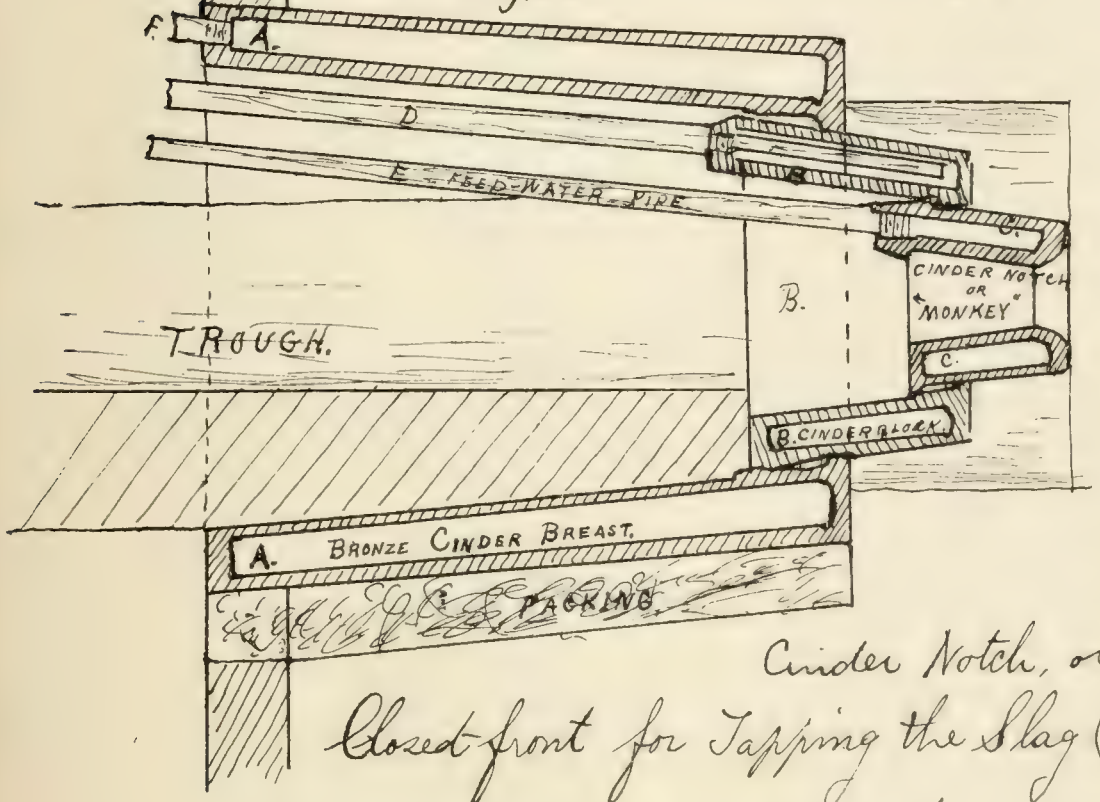


Fig. 30.

Cinder Notch, or Closed front for Tapping the Slag (or Cinder)

The three parts A, B. and C, shown in fig. 30 are hollow bronze casting through which cold water runs. The trough is usually made of clay to protect the cinder breast. E, D, and F are the feed water pipes for the "monkey", block, and breast respectively; the outlet pipes are not shown. The slag generally chills around the monkey, thus protecting it.

Bells.

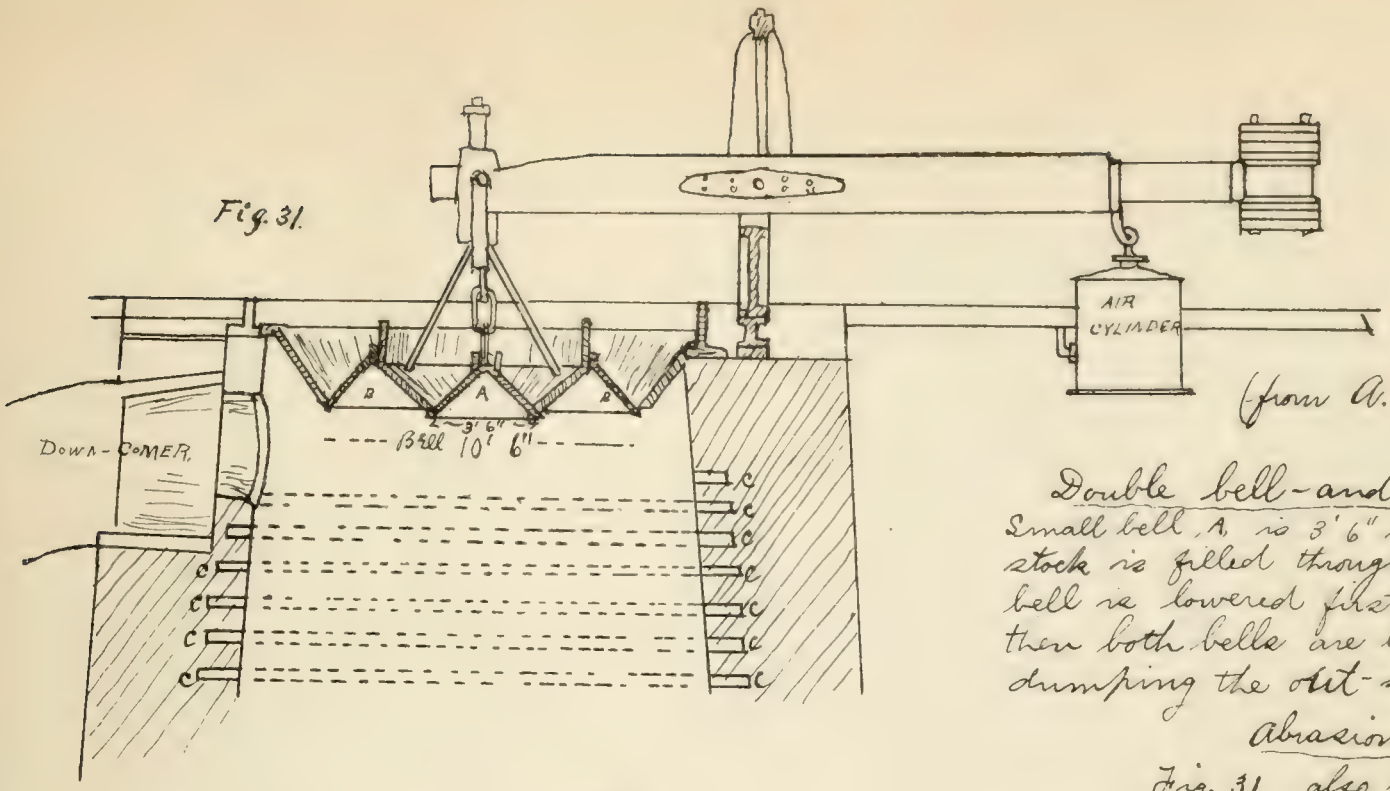


Fig. 31.

(from A. I. M. E. vol. XVIII, 390)

Double bell-and-hopper.

Small bell, A, is 3'6" in diameter - $\frac{1}{7}$ of stock is filled through it. This inside bell is lowered first, and then closed, then both bells are lowered together thus dumping the out-side one, B. B.

Abrasion Rings.

Fig. 31, also shows abrasion rings cc. cc, which are iron rings built into the brick-work to prevent the stock from wearing away the brick. They are of doubtful value as the contraction and expansion tears the brick-work.

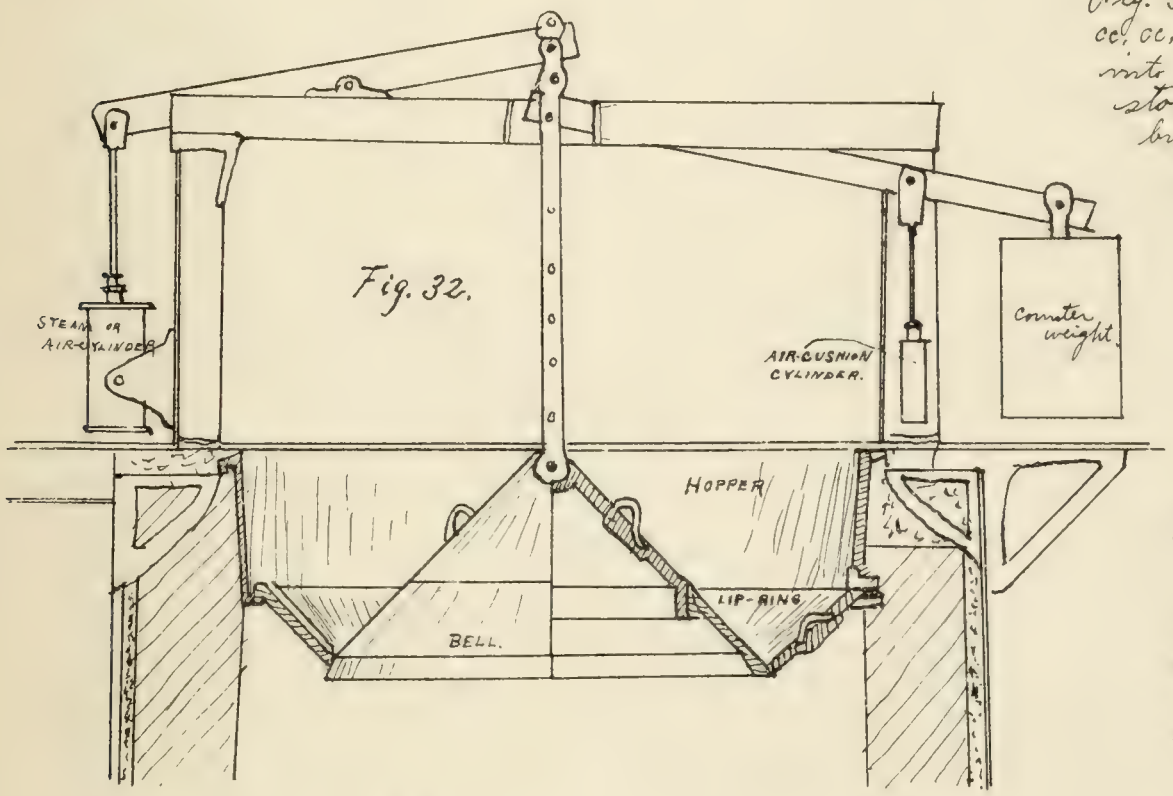


Fig. 32.

(Fig. 32.)

Single Bell and hopper Double lever system.

(from. Phila. Engineering Works, Ltd. catalogue 1893.)

The bell is lowered by the parallel link mechanism, and the "charge" of stock slides off into the furnace.

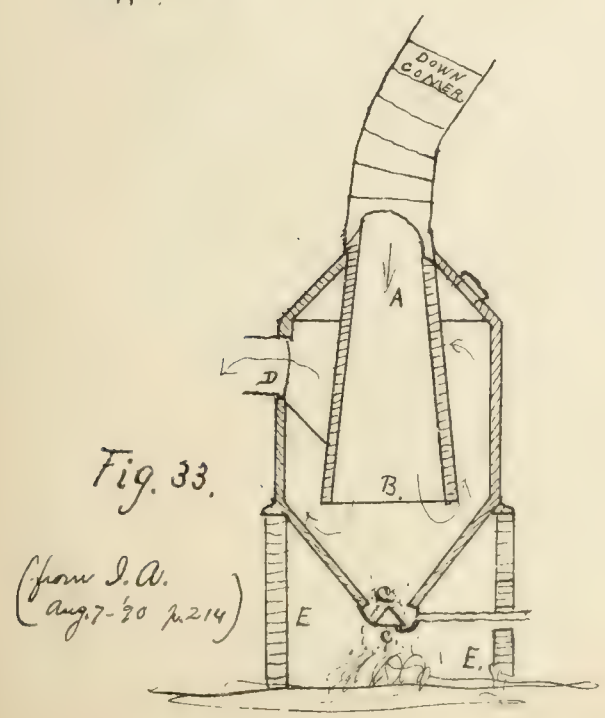


Fig. 33.

(from I. A. Aug. 7-'90 p. 214)

Dust-catchers. (Fig. 33.)

Fig. 33 shows the form of dust-catcher used by the Monongahela Furnace Co.

The downcomer after entering the dust-catcher increases in diameter, till the area at the bottom (B.) is just twice that of the top (A.) Thus the gas moves with half the velocity at B as it does at A. The dust settle to the bottom (CC) while the gas rises and goes out at D. EE is a circular brick wall on which the dust-catcher rests.

In another form of dust catcher the gas enters on the side near the top and is given a rotary motion.

Boilers.

The chief fuel used in the boilers and stoves is the waste gas from the top of the blast furnace. This is a very low grade of fuel as will be seen from the following table of gaseous fuels. Hydrogen, marsh gas, and carbonic oxide are the chief heat giving agents in all these gases.

Some analyses of gaseous fuels.

	Hydrogen H.	Marsh Gas. CH_4.	Carbonic oxide CO.	Heavily carburetted Hydrogen. C_xH_y.	Nitrogen N.	Oxygen O.	Carbon di-oxide CO_2.
Coal gas.	37.97 %	39.37%	3.97%	4.29%	9.99%	.61 %	4.1%
Water gas.	52.13 '	.76	38.06	—	2.83	.12	6.10
Producer gas.	.47	.58	21.73	2.95	66.86	—	7.41
Natural gas.	13.50	80.11	Trace	5.72	—	—	.66
Iron Furnace gas.	4.85	.34	24.44	—	55.42	—	13.96
Range of " " "	—	—	21.0 to 31.0	—	54.0 to 66.0	—	7.0 to 19.0

The Boilers are so mounted that they can be drawn by a grate fire while blowing in the furnace, or whenever the blast is off the furnace for any reason. As soon as the waste gases come in sufficient quantity they take the place of the grate fire. The quantity of gases is almost always greater than is needed for boilers and stoves; on this account boilers are usually chosen for simplicity, and ease of keeping them in order, and for safety rather than for great economy. Plain cylinder boilers, very long and of small diameter are much used, especially where there is plenty of room. For high pressures and economy of room sectional boilers, such as the Heine and Babcock and Wilcox boilers are much used. Usually in all these boilers a grate-fire (soft coal for fuel) is maintained all the time so that if the gas should stop coming for a little while it would readily ignite when it started again.

Four kinds of Boilers are shown on pages 22 and 23.

Fig. 34 is the French or Elephant boilers — simple, accessible, but takes up much room.

Figs. 35 and 36 show water-tube boilers; and fig. 36 shows such a boiler for burning furnace gases. Such boilers are generally mounted in pairs. The gas-main from the down-comer is either underground as is shown in fig. 36 or is overhead with a separate supply-pipe (or small "down-comer") for each boiler. The fire-doors for the coal are on the side while the gas enters at the front through the gas burner. The gas is burned in the chamber A.B. and passes up and then down through the battery of water-tubes and off through the flue.

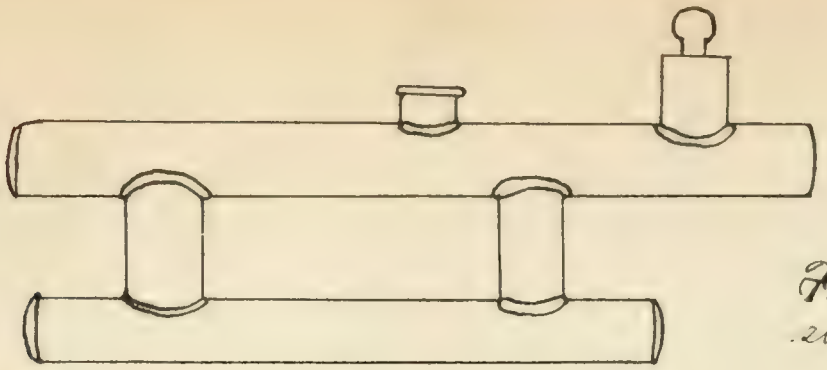


Fig. 34.

(Fig. 34.)
French or Elephant Boiler, showing only the cylinders

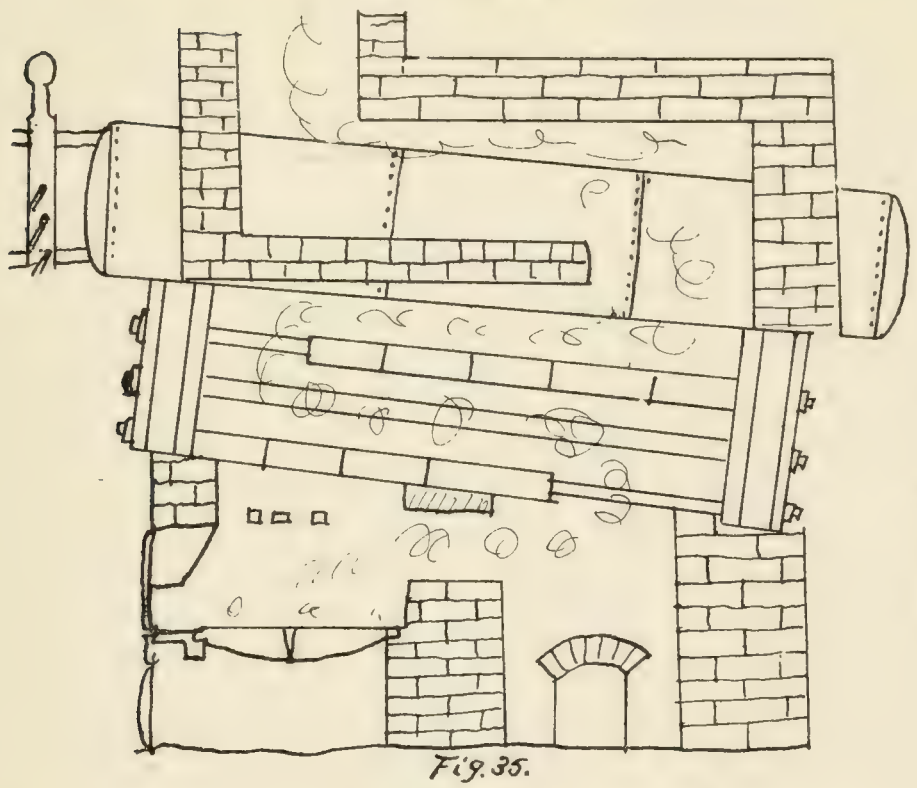


Fig. 35.

(from A.I.M.E. vol. XII, p. 943)
(Fig. 35)
Heine Patent Safety Boiler, showing boiler and method of setting for burning coal. For burning furnace gas the setting is similar to that shown in fig.

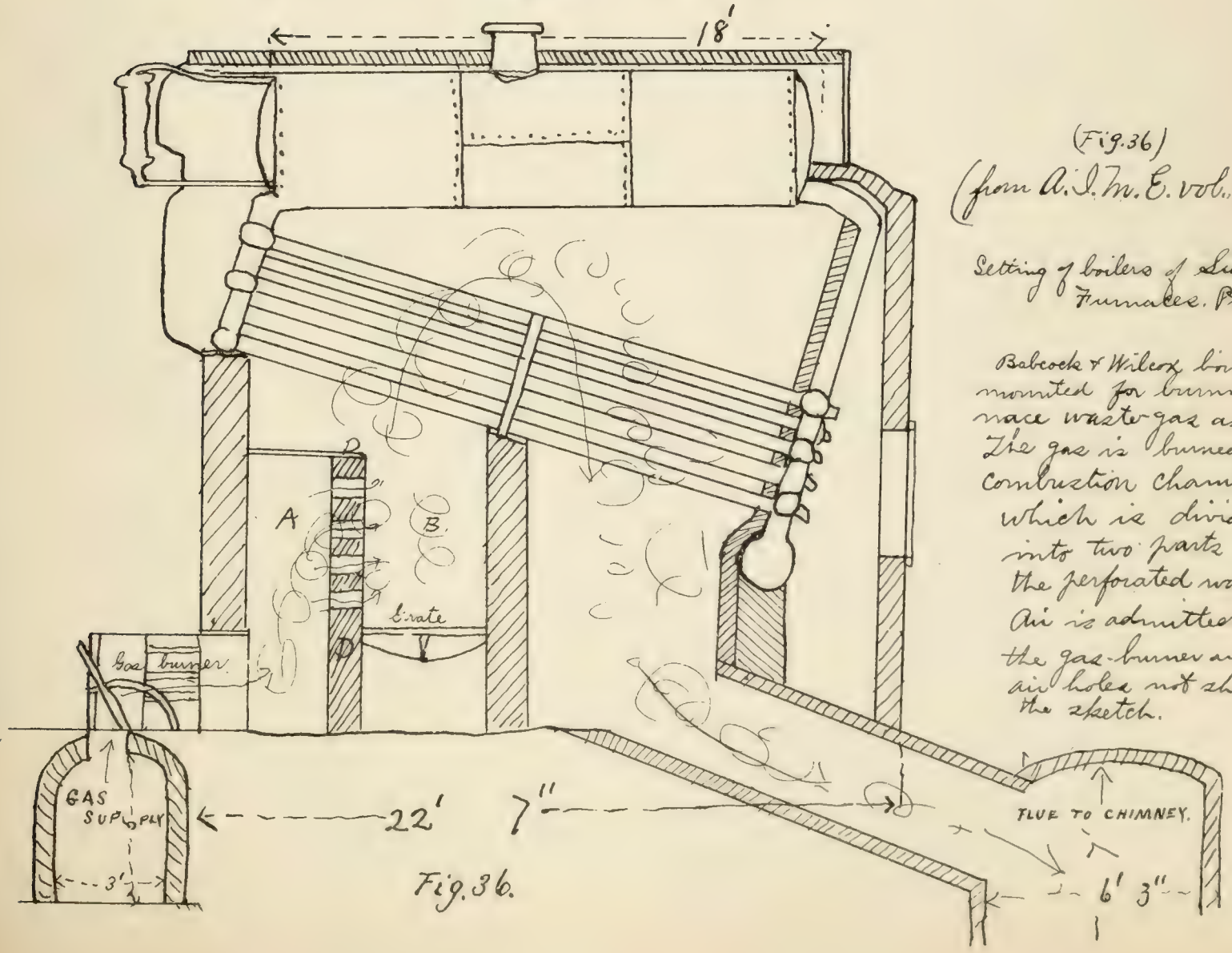


Fig. 36.

(Fig. 36)
(from A.I.M.E. vol. XIII, p. 45)
Setting of boilers of Lucy Blast Furnaces. Pittsburgh.

Babcock & Wilcox boiler mounted for burning furnace waste-gas as fuel. The gas is burned in the combustion chamber A.B. which is divided into two parts by the perforated wall D,D. Air is admitted through the gas-burner and through air holes not shown in the sketch.

Two Flue Type of Boiler Setting generally used for Blast Furnaces.

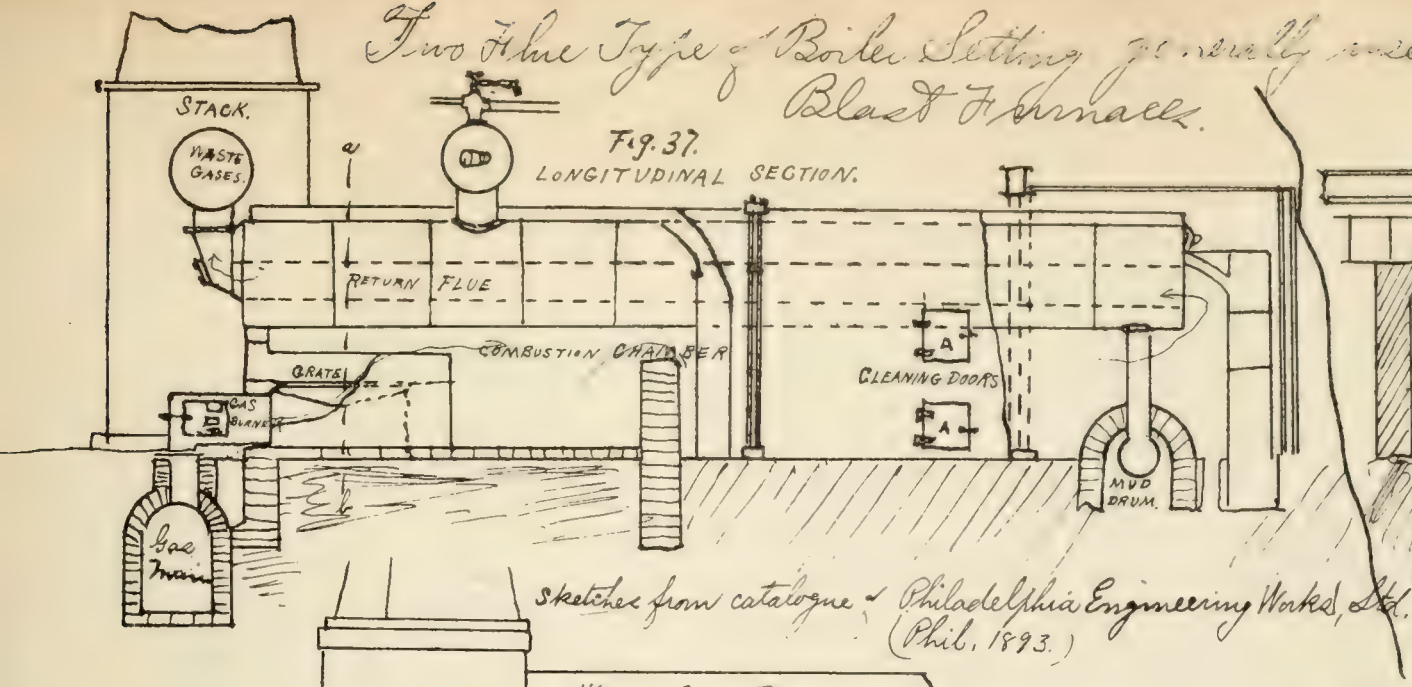
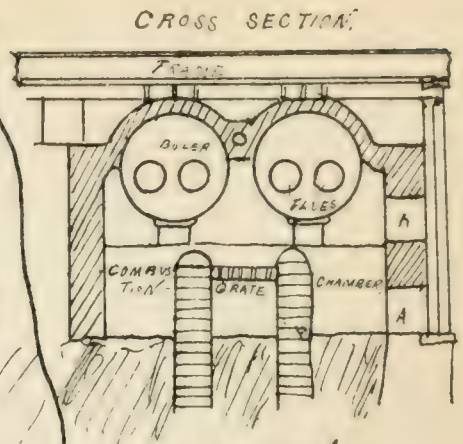
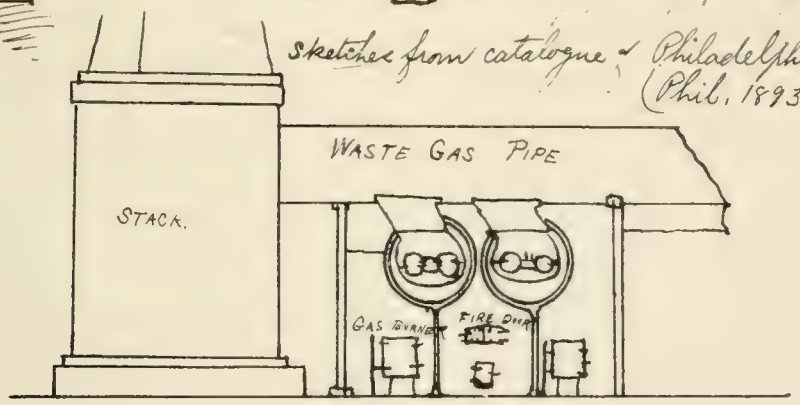


Fig. 37.
LONGITUDINAL SECTION.



SECTION ON a-b.
Fig. 38.

Sketches from catalogue of Philadelphia Engineering Works, Ltd. (Phil. 1893.)



FRONT ELEVATION.
Fig. 39.

Two-Flue Boiler.
Mounted in pairs - combustion chamber runs the whole length of boilers, and the gases return through the two flues and pass off up the waste-gas pipe & the stack.

Blowing Engines.

In modern blast furnace practice, with increase of volume, temperature and pressure of the blast, together with decrease of the amount and of the calorific power of the furnace gas, the economy in steam consumption has become a matter of much importance, and consequently blowing engines of good efficiency must be used. No class of machinery is subjected to more constant work with such irregular strains and such little time for examination and repair, than the blast furnace blowing engine. The engines for a single furnace are called upon to deliver from 5000 cu. ft. to 35000 cu. ft. of air per minute, compressed to from 2½ to 14 lbs. per sq. inch above the atmosphere. Roughly we may estimate the quantity of wind needed from the yield of the furnace in pig:-

100 cu. ft. air per min. yields 1 ton pig iron in 24 hours.
10 000 " " " " " " 100 tons " " " " "
30 000 " " " " " " 300 " " " " " "

The following rule gives approximate estimate of horse power needed, and assumes that we know the coke consumption for one ton of pig:-

A blowing engine of 2½ H.P. burns 1 ton coke in 24 hours.
" " " " 250 " " 100 tons " " " "
" " " 750 " " 300 " " " " "

Blowing engines are mounted in this country (1) :-
Horizontal direct with fly wheels - (also compound.)
Vertical " " " " - Single and duplex.
Vertical Beam engines.
Vertical direct with beams and fly-wheel - Duplex. (see fig. 40.

Blowing Engines. (cont.)

Figures on page

In the following extracts from a paper by Julian Kennedy (A. I. M. E., vol XII. p. 573 [1883]) are mentioned the principal types of blowing engines.

"The style of blowing engine most largely used in this country is the vertical engine with air cylinders above, cross-head between steam- and air-cylinders, and two fly-wheels, each having a wrist-pin in its hub, or in one arm. This kind of engine can be built cheaply, takes up little room and is very accessible. Its disadvantages are that the cross-head is liable to break, and that putting the wrist-pins in the wheels tends to set up vibrations in them".

"The Bethlehem Iron Co. have engines of this type, only they are horizontal and compound, the two cylinders being side by side. The weight of the piston is taken up by steam pressure applied through hollow piston rods, and pressure chambers on the under side of the piston."

"A vertical double engine is also used, with air cylinders above and the other parts arranged in this order downwards :- steam-cylinder, cross-head- and cranks; the latter are at right angles to each other. This type is also used as a horizontal engine. They avoid wrist pins in flywheels, and long cross-heads. These vertical engines take up less room but are very high and liable to vibration."

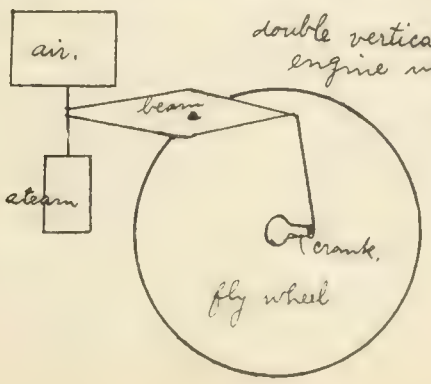
"The air-valve is the weak point in blowing engines; the limit of speed that the air-valves will work must be that of the machine."

Vertical beam engines cost high but are very strong and durable when well built.

The steam-piston of a blowing engine is required to do the most work when it has the least power. This difficulty has been largely overcome by use of duplex engines. The Maryland Steel Co. use vertical direct duplex engines with two beams and one flywheel. A rough sketch (fig. 40) of the arrangement is given below.

The blowing of more than one furnace with one engine is not now approved of, because (1st.) a break-down would be much more complicated if it affected more than one furnace; and (2d.) a furnace with larger percentage of coarse ore in it would get more than its share of wind, and hence produce more iron, while the other one, or more, furnaces would not get their share. The plan now adopted is to give each furnace its blowing engine, or further to give a large furnace two or three engines to itself.

Equalizer. To equalize the pulsations of the blowing engine so that the furnace shall receive a constant blast, a long pipe of sheet iron of large diameter is used to connect the blowing engine with the furnace. The old fashioned weighted piston is a leaky affair and has been given up.



double vertical direct blowing engine with beams and fly-wheel.

Fig. 40.

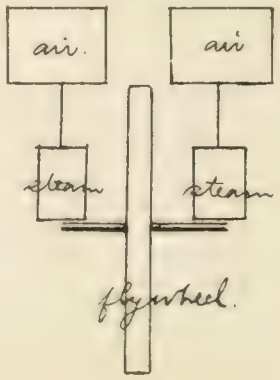
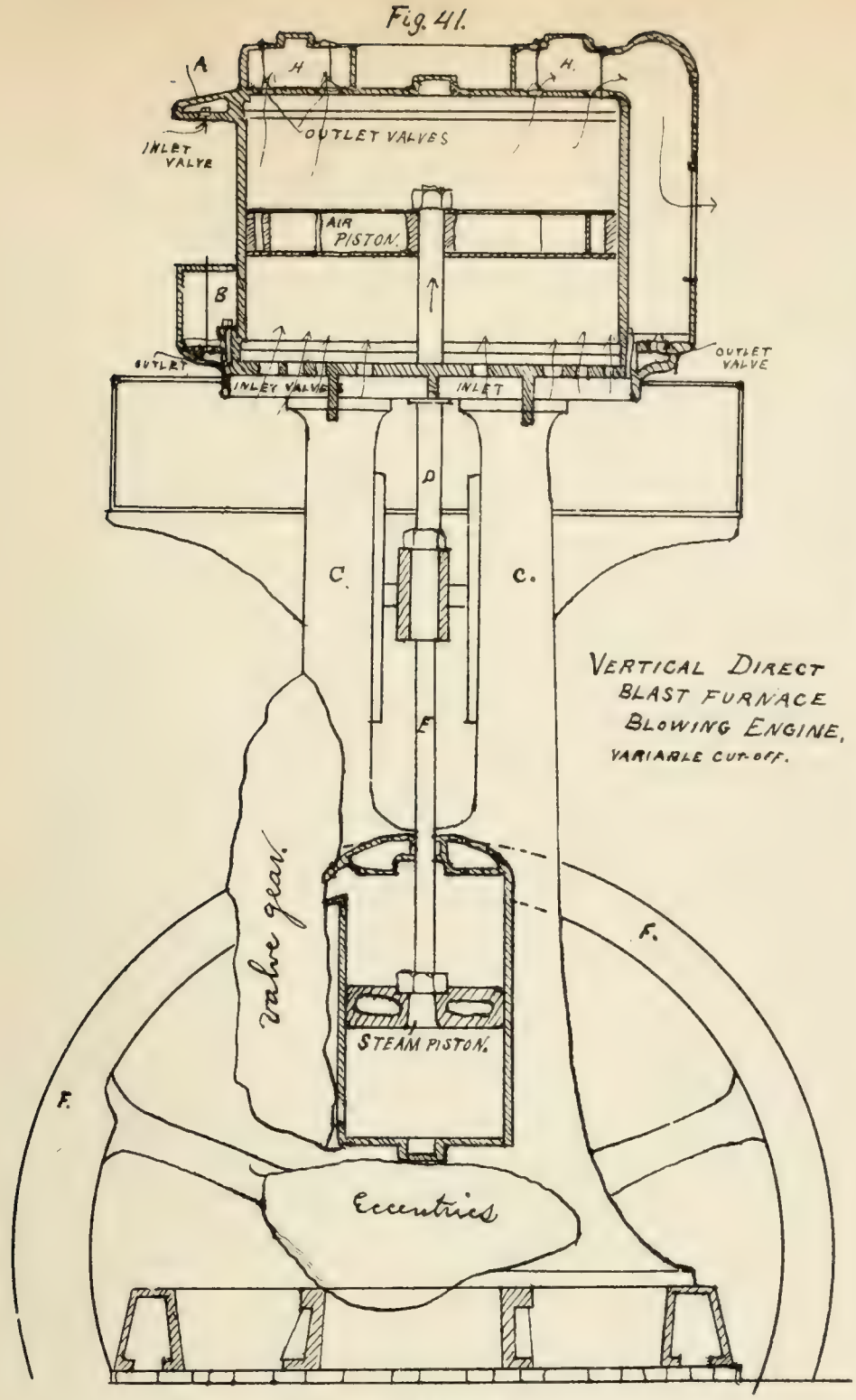


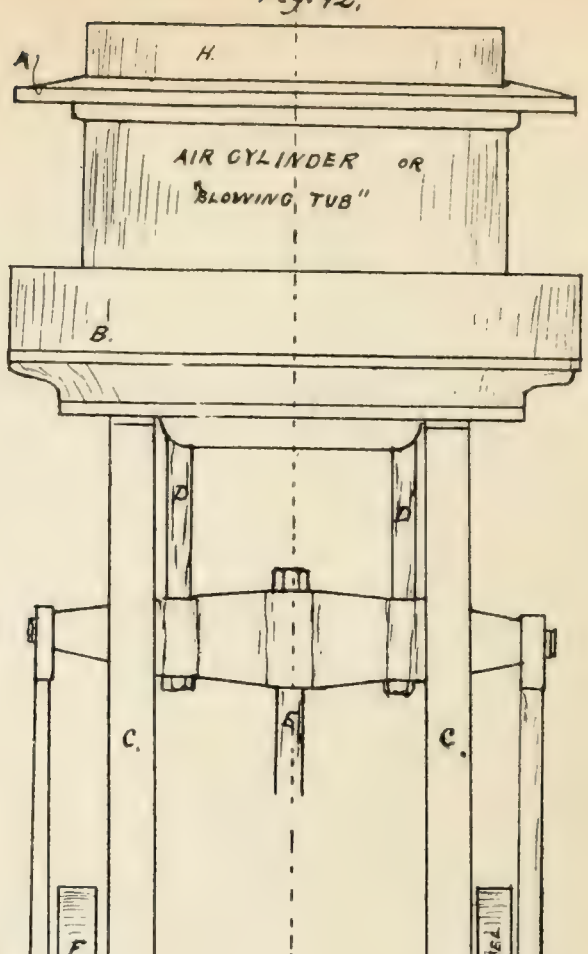
Fig. 41.



VERTICAL SECTION.

VERTICAL DIRECT BLAST FURNACE BLOWING ENGINE, VARIABLE CUT-OFF.

Fig. 42.



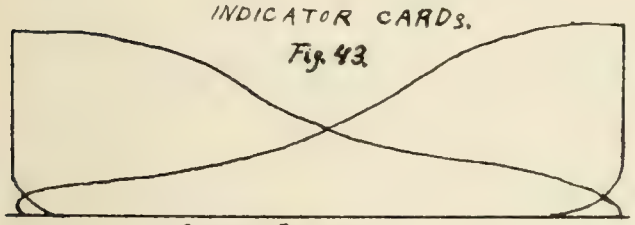
ELEVATION.

Fig 41 shows arrangement of cylinders and is a vertical section on dotted line shown in fig 42 which is a partial front elevation. The air piston has two piston rods and the steam piston one rod. This strengthens the long cross-head, and a closer connected engine is obtained.

Fig. 45 shows section of air outlet valve. L is the leather disc valve backed with a steel disc (S) $\frac{1}{16}$" thick. Fig 46 shows inlet valve L is the leather disc. Both valves seat by gravity. Both are shown open.

INDICATOR CARDS.

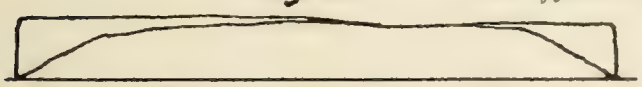
Fig. 43.



STEAM CYLINDER.

Steam cylinder, 36 in. diam., 48 in. stroke.
Revolutions, 34. Cut off at $\frac{1}{4}$ stroke.
Spring 40 lbs. Steam pressure 60 lbs. Throttle wide open.
av. effective pressure, 30.6 lbs.

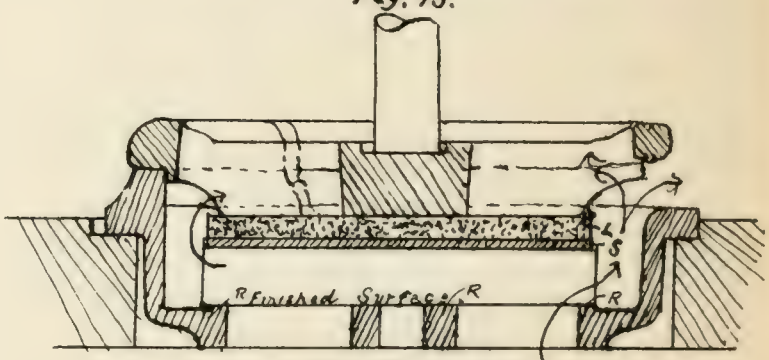
Fig. 44.



BLOWING CYLINDER.

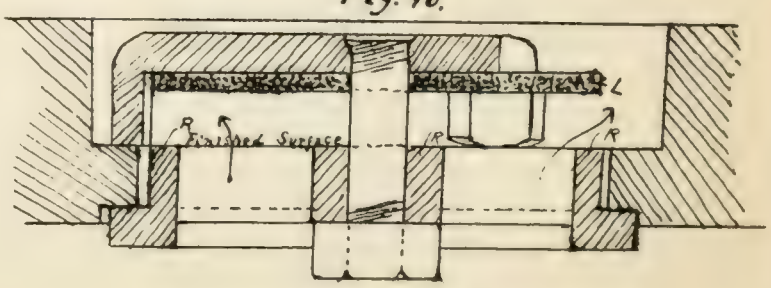
Blowing cylinder, 48 in. stroke, 84 in. diam.
Revolutions, 31.
Spring, 10 lbs.
Blast pressure by gauge, 4.5 lbs.
Average " 3.92 lbs.

Fig. 45.



OUTLET VALVE.

Fig. 46.



INLET VALVE.

(all figures on this page are from catalogue of Phila. Engineering Works, Ltd. 1893.)

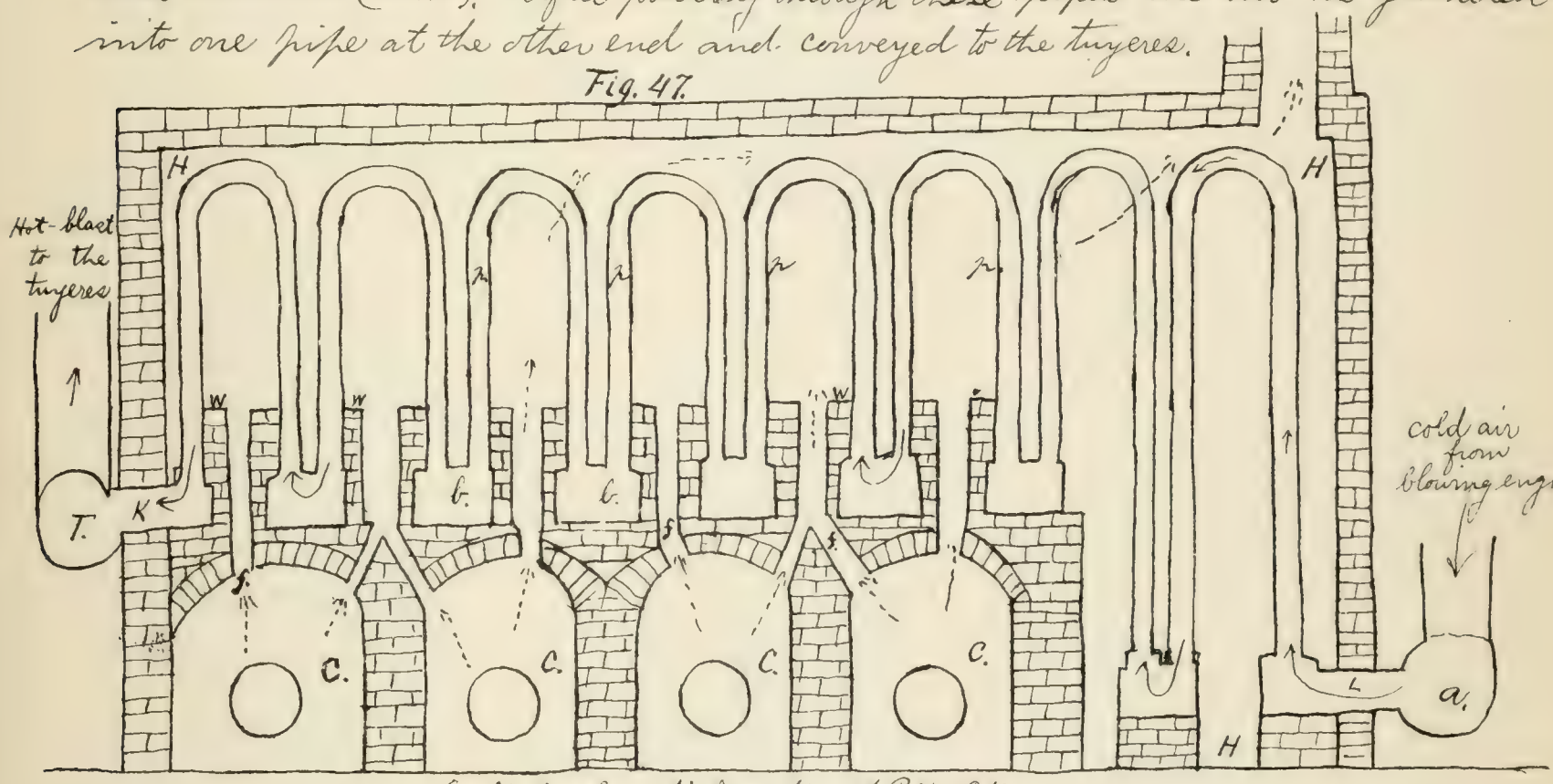
Stoves.

The earlier blast furnaces were blown with cold air, but later a hot blast was used with a view to saving fuel. The air from the blowing engines (the "cold-blast," or "the wind".) passes through the stoves, or "hot-ovens," which have been heated by the waste-gases from the furnace. From the stoves the "hot-blast" passes through the hot-blast pipe to the bustle-pipe and into the furnace. There are two classes of stoves, pipe stoves and brick stoves. (In the drawings of the stoves, the dotted arrows indicate the flow of the gases, and solid arrows that of the air.

Pipe-Stove. (Fig. 47)

In the pipe stove the action is continuous. The cold air from the blowing engines enters at one end (a) of a branching battery of pipes which are within a large brick chamber (H,H,H). After passing through these pipes the air is gathered into one pipe at the other end and conveyed to the tuyeres.

Fig. 47.



Longitudinal vertical section of Pipe Stove.

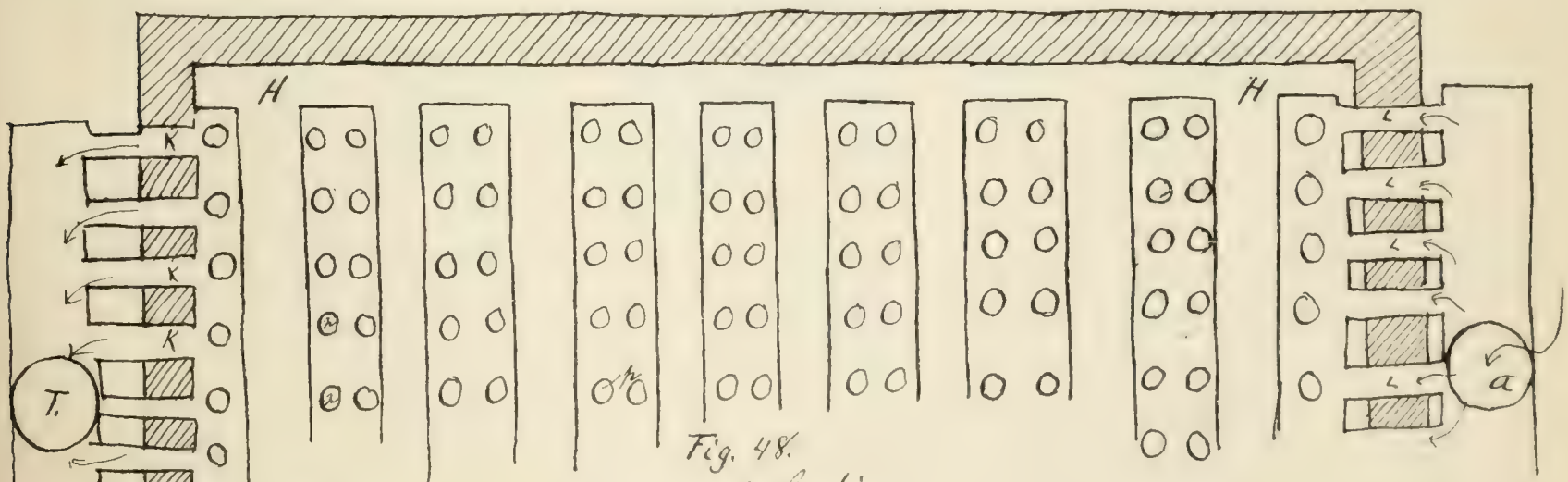


Fig. 48.

Horizontal Section.

These sketches give a general idea of the Pipe Stove as used by the Lehigh Valley furnaces.

a. - cold air distributing-pipe.
b. - bed pipes.
C. - combustion chambers.
f. - flues leading hot gases and flames to the pipes p. p.
p. ox-bow pipes - (iron)
W. brick wall to guard from excessive heat.
T. Hot-air collecting pipe.

Stoves. (con.)

During the passage of the air through the battery of pipes (P, P, P,) it is heated by the combustion of furnace waste-gases in the space around the pipes, the heat of combustion being conducted through the walls of the iron pipes to the air blast. The pipe stove is being replaced by the brick stoves.

Brick Stoves.

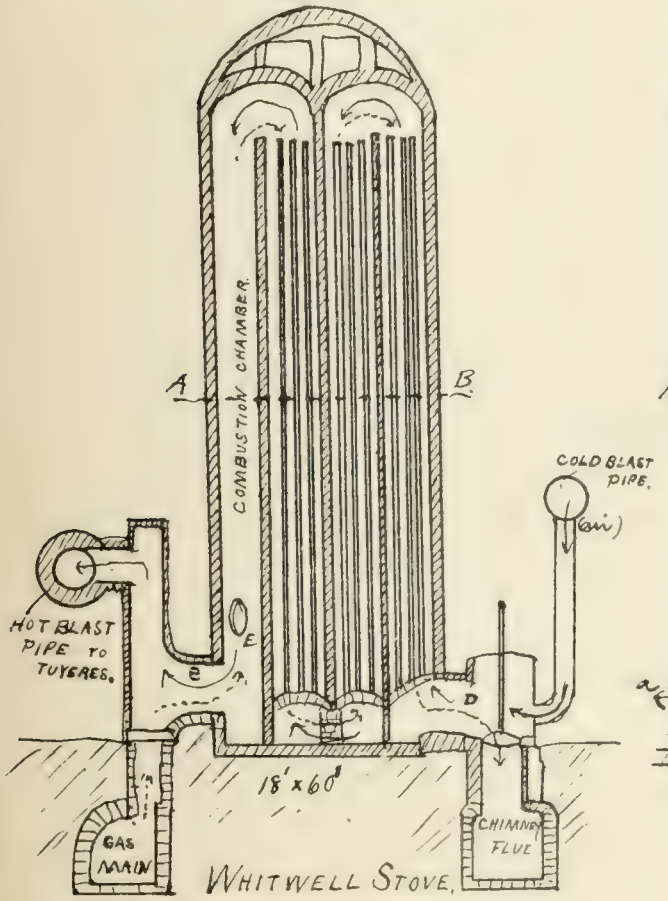
Brick stoves are mounted in groups of three or four for a furnace. The action of these stoves is intermittent, there being two periods in the use of them; 1st. the storing-up-heat period; 2d, the giving-out-heat period. When one stove is giving out heat, the other two or three are storing up heat.

The storing period is when the waste gases from the blast furnace are burned with addition of air in the stove, and the heat of this combustion is absorbed by the walls of the fire-brick flues, which are heated to strong redness. The giving-out period is when the blast (the "cold wind") from the blowing engine is passed through these red-hot flues on its way to the tuyeres.

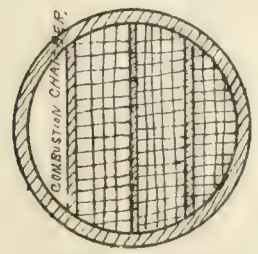
The stoves are made of fire-brick, are circular in section, and are encased completely without a boiler-iron shell.

In the Whitwell stove, fig. 49, the gas enters at c burns in the combustion chamber into which air is admitted through air ports, E. Then the hot gases pass down through the checkerwork of brick, up and down again and out at D, making 4 passes. The cold air takes reverse course.

Fig. 49

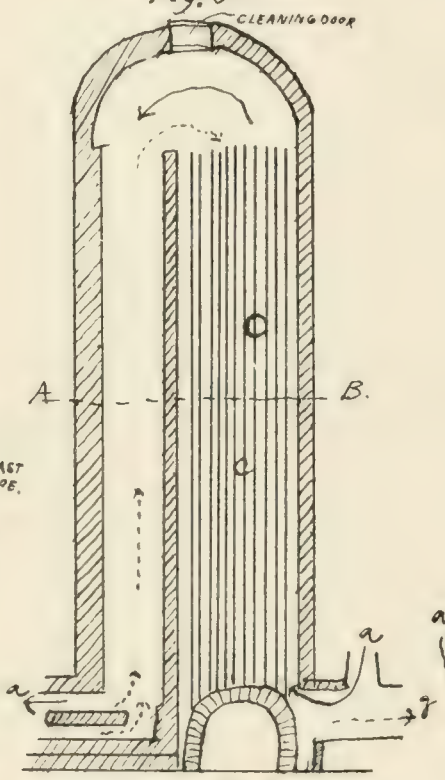


WHITWELL STOVE.
(a. I. M. E. vol. IX. p. 480.)

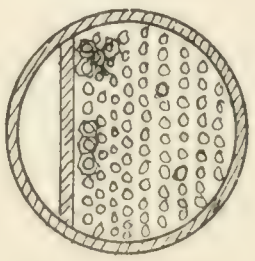


SECTION ON AB.
"4 pass" stove.

Fig. 50

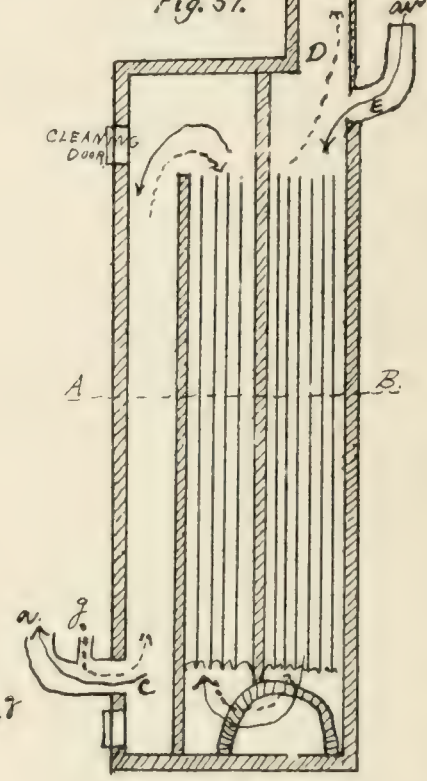


COWPER STOVE.
(a. I. M. E. vol. X. p. 495)
21' x 72' 6".

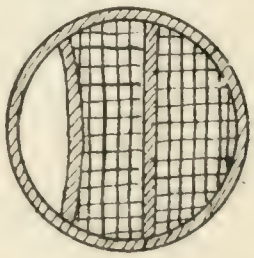


SECTION ON AB.
"2 pass" stove.

Fig. 51.



GORDON 3 PASS STOVE.
23' x 60'
(a. I. M. E. XII, p. 159)



SECTION ON AB.
"3 pass" stove.

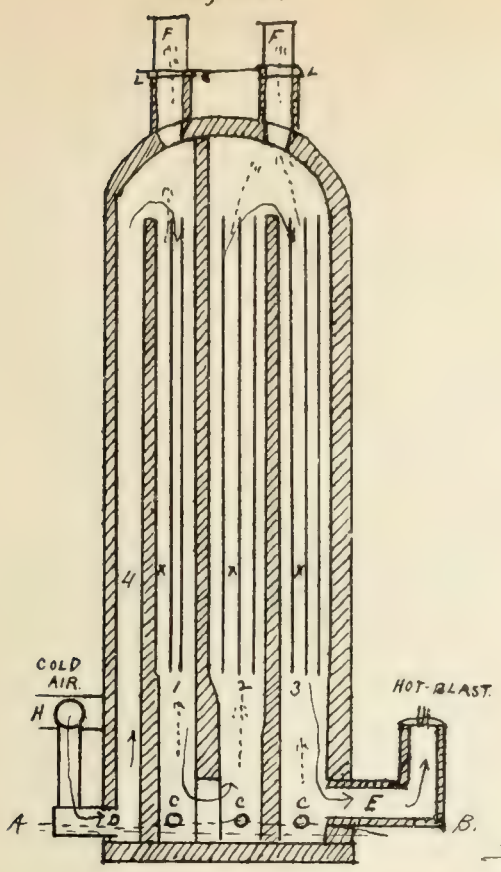
Cowper Stove.

The Cowper stove shown in fig. 50 is the type used at "D" and "E." furnaces, Edgar Thomson works (a. I. M. E. vol. X - 1882) The gas makes one up, and one down pass, and the air does the same in the reverse direction. The flues in the "regenerator" C, are round instead of square. These openings are 6" in diam. and are in the centre of hexagonal bricks 16" across ⬡

Gordon Stove.

The Gordon stove (fig. 51) is a three pass stove. The gas enters at C, ascends, descends and ascends again and passes out of the small stack at the top (D). The air enters at E makes the order passes in reverse

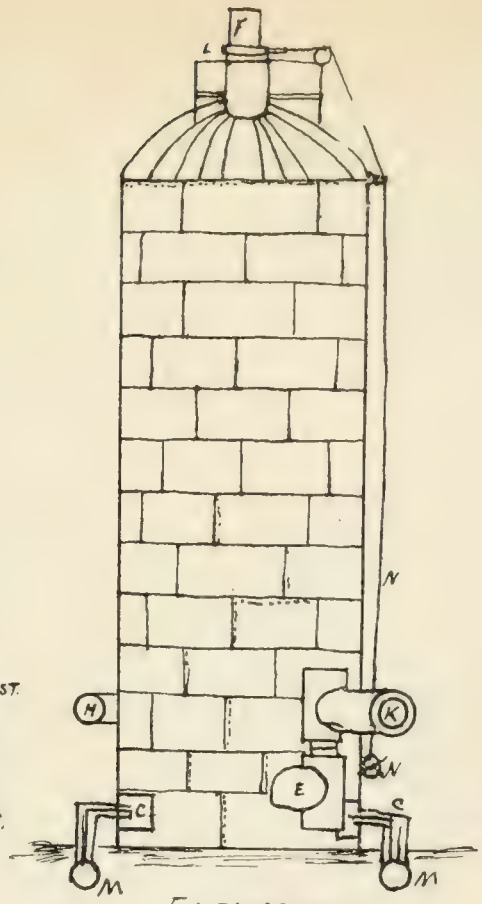
Fig. 52.



VERTICAL SECTION.

SECTION ON AB.

Fig. 53.

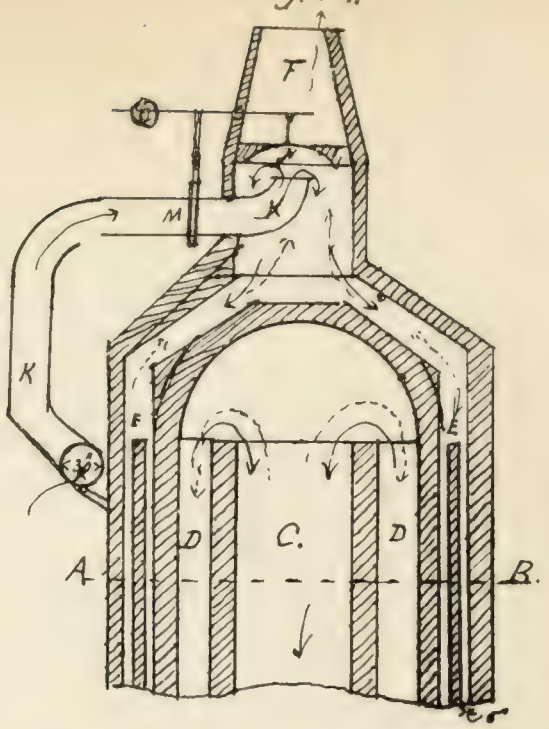


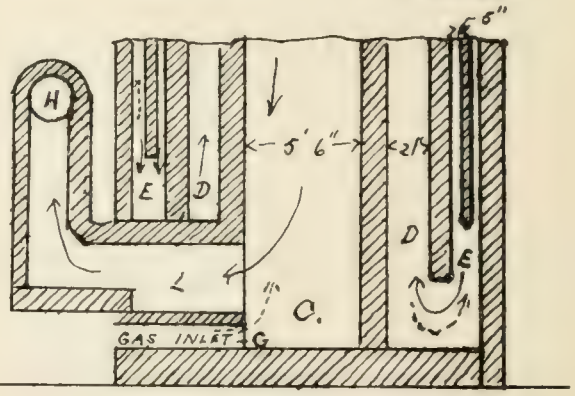
ELEVATION.
(20'x60')

Hugh Kennedy Stove.
(a. I. m. E. XXI,-720)

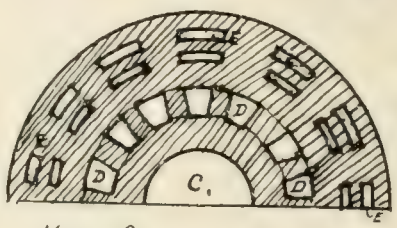
The Hugh Kennedy stove (fig. 52 and 53) is a modification of the Whitwell stove (fig. 49.) The gas, instead of burning in only one combustion chamand making four passes, burns in three chambers and makes only one pass, with a natural draught. The gas from the gas-mains M, M, enters through the openings C, C, C, and is burned in the three chambers, (1, 2, 3) and passes out of small stacks, F, F. The cold air, makes four passes as in the Whitwell stove. It enters at D, passes up through 4, down through checker work, X, in 1, up, and then down again and out at E, through hot-blast pipe K (fig. 53). L, L, are the valves in stacks which are closed by chain (N, N) when the blast is in the stove. At Isabella Furnaces, Pittsburgh, Pa., a plant of three of these stoves has been in use (1890-92) for two years and has been very satisfactory. (For discussion on this stove see A. I. M. E. XXI, p, 720)

Fig. 54.





VERTICAL SECTION.



HALF-SECTION ON A-B.

18'x60'
3 PASS STOVE.

Massicks and Crooke's American Patent Hot-blast Stove.
(A. I. M. E. XIX – 1036)

a set of three stoves of Massicks and Crooke's design cost in 1890 as follows:-

3 stoves 16'6"x60'
$17,521.00 (average cost)
3 stoves 18'x60'
$19,934.00 " "
3 stoves 19'6"x65'
$23,839.00 " "

Massicks and Crooke's Stove.

This is a three pass stove which was first used in England. Fig. 54 shows the stove as designed for american furnaces and patented in this country. This stove differs from the preceding ones in construction; the gas enters

Stoves (con.)

at G and passes directly to the centre of the stove, and ascends through a round chamber c; then it descends through the flues of an annular chamber D.D, and then up through the flues of a double annular chamber E,E and out of stack, F, at top. The air enters through cold-blast pipe, K K, at top and passes through the stove in the opposite direction, and goes off into the hot-blast pipe, H. This type of stove has been used with success at the furnaces of Shoenberger, Speer, & Co. Pittsburgh, and Illinois Steel Co., Chicago, and at many other furnaces.

The last three stoves mentioned have independent chimneys for each stove thus diminishing the cost of the plant. The other stoves described require a large central stack of great height; this gives great draught in the stoves. The number of "passes" which the gases make through the stoves is the principle point of difference between the various types. The first pass is the most intensely heated and the efficiency of the bricks diminishes as their distance from the combustion point increases.

Some Actual Results with Brick-Stoves.

The efficiency of a brick hot-blast stove depends very much upon the way it is managed, as well as upon its construction. The following results obtained with a four-pass stove that had been in constant use for 18 months, show the effects of burning all the gas in the first, or combustion, chamber, and of burning part of the gas in the first, and part in the other three chambers (called "burning the gas back"). The burning of the gas is regulated by means of the air-ports which admit air to the different chambers. The stove was one of a set of four 22x70' Whitwell stoves (see fig. 49) for an 85-foot furnace yielding 250 tons of iron per day. Gas was burned in the stove for three hours and the blast (29,000 cu. ft. of air per minute) was blown through for one hour.

	On.	Off.	Loss	% dif.	Av. while "on"
Gas burned in first chamber only	1104.6° F.	889.7°	201.9°	19.0%	997.2°
" " " " " and back also	1157.3° "	932.2°	212.2°	18.5%	1044.8°

"On" means the temperature of the blast when it was first put through the stove; "off" is the temperature of the blast after air has been blown through the stove for one hour. The "loss" is the number of degrees the temperature fell off during the hour. "Av. while on" is the average of the temperature of the blast for the hour. The "% dif." is the per cent of the falling off from the highest temperature. These figures are the averages for one week's observations.

In another stove of the same kind except that it had a larger combustion chamber, and a different kind of a gas-inlet valve (all the gas being burned in the first chamber) higher temperatures of blast were obtained. The average temperature of the blast while "on" this stove was 1109.1° F. (av. for one week.) The following table gives the temperature and analysis of the escaping gases in this 2d. stove (#2 Stove.)

Time	Temperature	CO_2	CO	Oxygen
5 min. after gas was put into stove	890°	20.5%	0.0%	3.5%
1 " before blast " " " "	1030°	19.5%	0.0%	4.0%

Stoves (con.)

The preceding table of analyses shows that all the CO in the furnace gas was burned, but it also shows that a little too much air was admitted at the ports.

The following results from the same stove (#2 stove) show how the temperature decreases during the hour.

Time.	Temp.	Lapse in time	Loss in degrees
2.55 P.M.	1100.0°		
3.05 "	1100.0°	10 min.	0°
3.15 "	1080.0°	10 "	20°
3.25 "	1060.0°	10 "	20°
3.35 "	1050.0°	10 "	10°
3.45 "	1030.0°	10 "	20°
3.50 "	1010.0°	5 "	20°
	Total time = 55 "		Total loss = 90°

Revolutions of blowing engine = 38
Cu. ft. of air per min = 29000
Pressure of blast = 8 lbs.
Yield of furnace for the day = 249.69 tons.
Temperature of gas at top of furnace = 600°
Si in the iron: av. for day = 1.57%
(Making Bessemer iron)

(Tests made at "C" Furnace, Maryland Steel Co., Sparrow's Point, Md. - Feb. 1893 - R. H. S.)
The temperatures of the blast were taken at a tuyere-cap with a "Standard" pyrometer (Edw. Brown's patent).

Chimney or Stack.

Where a single large stack is used for the stoves it is generally used for the boilers also. The stacks are generally round, made of plate iron, and lined with fire-brick. The heights vary from 70' to 235 feet.

Pumps.

Very much water is needed around a blast furnace, not only for the boilers and condensers, but also for cooling the furnace walls, and pumps of large capacity are required. They are usually placed in the engine house, with the tanks outside. The pressure required for the water for the tuyeres and cooling blocks, etc., is obtained by use of a high tank. Often the water connections are so arranged that the feed-water for the boilers (at 80-140 lbs. press.) can be used for cleaning out the bosh-blocks and other coolers when they become plugged up. A little fish caught in the inlet pipe of a cooling block has been known to cause the loss of the block. All such obstructions should be immediately forced out.

Stock House.

For the protection of the ore, fuel, and flux, from rain and snow, a stock-house is built directly behind the furnace or furnaces. It is open at both ends, and has tracks, usually on a trestle, running through it lengthwise. The stock is dumped from the cars & the bins below. To save rehandling, "bunkers" that allow the stock "buggies" to run in beneath them, are used; in this way the ore, coke, etc. are drawn off into the buggies, otherwise the stock must be shovelled into them.

Scales.

The scales for weighing the ore, flux, and fuel, are placed in the stockhouse near the elevator. They are generally double platform-scales with multiple beams.

Elevator and Filling Arrangement.

The most common way of putting the ore, flux, and fuel into the furnace is by means of two-wheel barrows or small four-wheeled cars. These are filled in the stock-house, wheeled to the scales, and then to the elevator, and hoisted to top of furnace where they are dumped into the hopper. The elevator is double - loaded buggies going up while empties come down on other side. In some cases all the filling of the furnace and lowering the bell is done from the ground by using an incline with automatic dumping arrangement.

Casting House.

The casting house, either a brick or iron structure, is built in front of the furnace; often its roof extends back of the furnace to the elevator. The floor of the casting-house, the "pig bed" (see fig. 12), is either of common sand, or is composed of iron moulds, called "chills". The sand bed must be moulded up before each cast; with chills the bed is ready for casting as soon as the pig iron of the previous "cast" is removed from the bed. Where the pig-iron is to be made into Bessemer steel and the converter is near the furnace, the iron is usually tapped from the furnace into "direct-metal" ladles which convey the iron, called "direct-metal," to the Bessemer plant. Moulten iron has been carried in these ladles, which hold from 15 to 18 tons, for several miles. (In making some large castings the Maryland Steel Co. has "taken iron direct" from the furnace to its foundry and there poured it into the moulds.) When iron is cast in the pig bed it is called "pig-iron", and each "pig" must be broken away from the "sow", carried from the bed and loaded on a car.

Disposal of Slag.

The blast-furnace slag is used for filling-in around the furnace plant, for ballast on railroads; for making mineral wool, cement, and building blocks, or bricks. It is either run into large moulds near the furnace, and removed when cold, or else run directly in large "ladles" or slag-cars, and poured out on the slag dump.

Tracks.

Car tracks must be laid about the furnace so that the stock can be readily brought in, and the iron and slag carried away. Small locomotives are generally used for this work.

	Porosity	Strength	Purity
Charcoal	XX	—	XX
Coke	X	XX	
Anthracite		X Decrepitates	

2. Materials for Smelting.

The materials for making iron in the blast-furnace are ore, limestone, and fuel. The fuel may be coke, anthracite, charcoal, or, more rarely, bituminous coal.

Iron Ores.

If ore is mixed with much fine dirt and sand, it can be washed with a log washer, which can be combined with jigs for coarser particles and with hand-sorting for the lumps. Ores containing much water, CO_2, or sulphur or which are very compact may be roasted (see Jips. 7-10.)

For analyses of iron ores see page 33.

Limestone.

For most purposes limestone should be as free from silica as possible, and must be free from phosphorous and sulphur. Dolomite with high percentage of MgO is often used with advantage, but where sulphur is to be eliminated pure limestone is preferred. Burning limestone previous to charging is not found as advantageous as might at first appear.

Charcoal.

Charcoal is made in three ways. First:- Wood is piled, covered with turf, and charred. The charring requires from ten to twenty days, and the yield is about 22% by weight or 50% * by volume. This process is known as the Meiler Process.

Second:- The wood may be charred in kilns. The charring requires six to ten days; the yield is 35% by weight. *

Third:- The wood may be charred in retorts. By this process the products of distillation may be saved. *

The following figures on the cost of charcoal per bushel at the works, when wood is $1.89 per cord cut and piled in the woods, are taken from the Journal of Charcoal Iron Workers vol. VI, p. 212 :- Meilers $0.061 per bu.; Kilns $0.0533; Retorts $0.0503 The meilers are in the woods and the charcoal is carted to the works, while the kilns and retorts are at the works, and the wood is carted. No account is taken of the value of the products of distillation

From several points of view charcoal is the best blast furnace fuel; namely, on account of its low ash and sulphur, and its great porosity. But it has so little strength that it crushes badly under the weight of the charge. For a long time, 30 feet was supposed to be the maximum height for a charcoal blast furnace, but now furnaces 60 feet high are in use. Six per cent. of the pig-iron made in the United States in 1892 was made with charcoal (Mineral Industry, 1892, p. 278.)

* The yield of meiler charring is 33 bus. charcoal per cord of wood; kiln charring yields 45 bus. per cord; retort charring yields 58 bus. per cord. (see Journ. Charcoal Iron Workers, vol. VI, p. 211)

The Principal Ores of Iron Dominion
Localities, chiefly in the United States.

	Magnetite. 1.	Magnetite. 2.	Magnetite. 3.	Magnetite. 4.	Magnetite. 5.	Hematite. 6.	Hematite. 7.	Hematite. 8.	Limonite. 9.	Limonite 10.	Limonite 11.	Siderite. 12.	Clay-iron-stone. 13.	Black-band iron ore. 14.	Franklinite 15.	Titaniferous iron ore. 16.	Manganese Ore. 17.	"Blue Billy" 18.	Hematite 19.	Hematite "Specular" 20.	Mesabi Hematite. 21.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Fe	59.23	45.87	46.42	54.30	68.24	64.38	65.28	44.40	48.99	52.82	40.61	43.05	33.62	36.20	48.77		2.26	47.35	56.28	60.33	61.22
FeO	25.34						2.32		.30	.34	4.93	54.39	39.92								
Fe_2O_3	56.37						91.45		67.77	74.88	53.93	1.07	3.60								
Fe_3O_4	81.71	63.3	62.20	74.90	94.2						CO_2 3.66			organic matter 10.46	Zn. 7.10	69.34					
SiO_2	7.63	24.89	26.0		4.43	4.27	3.99	13.9	11.94	6.62	14.37	2.11	7.12	1.93		5.40	11.35	8.70	8.00	4.44	5.80
Al_2O_3	3.08				0.28	0.91	1.40	5.99	4.10	3.30	9.36	1.46	7.86	1.23		9.29					
Mn.	a34	a.295		Mn_2O_3 1.53				MnO 0.19	0.65		MnO 1.26	MnO 3.25	MnO .96	1.97	12.81		47.03				0.539
CaO	4.09	9.74	1.11		0.14		0.51	5.85	1.60	0.82	1.03	0.54	7.44	2.44		0.39					
MgO	0.27		2.70				0.22	2.69	0.48	1.02	0.52	0.54	3.82	1.39		3.35					
P.	1.067	0.009	0.004	0.008	0.017	a057	0.252	0.53	0.413	0.241	0.126	0.115	P_2O_5 1.86	0.29		Tr.	0.017	0.008	0.040	0.039	0.055
S.	0.113	0.041	1.672	0.040		0.074		0.31	0.152	0.139	0.227	0.045	FeS_2 0.11	0.18		1.21		2.35	a39	0.13	
TiO_2	0.09															11.60					Combined water 3.99
H_2O										10.49	10.03	CO_2 3534		CO_2 30.77				Moisture 14.40	Moisture 3.00	Moisture 4.18	Free water 6.84

1. New Jersey – Census 1880 vol. XV.
2. Cranberry, N.C. – Mineral Resources, 1886, p. 82
3. Cornwall, Pa. " " 1883, p. 270
4. Dannemora, Sweden (Roasted, Dürre, p. 9.
5. Port Henry, N.Y. Mineral Resources, 1886.
6. Lake Superior Mine. Census 1880. vol. XV, p. 425
7. Iron Mt., Mo. (Unwashed) – A.I.M.E. vol. III, p. 377.
8. Clinton ore, N.Y. – Mineral Resources 1886.
9. Anaconia, N.Y. – Census 1880 vol. XV.
10. Shelby Iron Co. Ala. – " " "
11. Shepard's Bank, Ky. Census 1880. vol. XV, p. 800
12. Hellerstown, Pa. " " "
13. Cleveland ore, England – Dürre, p. 135.
14. Shelton Mine " – "
15. New Jersey. " p. 29.
16. Sickles' Mine, N.Y. " p. 25
17. St. Croix, Wis. Mineral Resources 1886.
18. "Blue Billy" from Monumental Chem. Co. used by M.S.Co. Sparrows Point.
19. "Cuban ore" from Juragua Mines (Dec. 1893) Cuba. (R.H.S.)
20. "Elba ore" – (M.S.Co. March '92) Isle of Elba (R.H.S)
21. Mesabi Iron ore from Mesabi Range Minn. – the above analyses is the "average of averages" (A.I.M.E. vol. XVI, 676)

BEE-HIVE COKE OVENS.

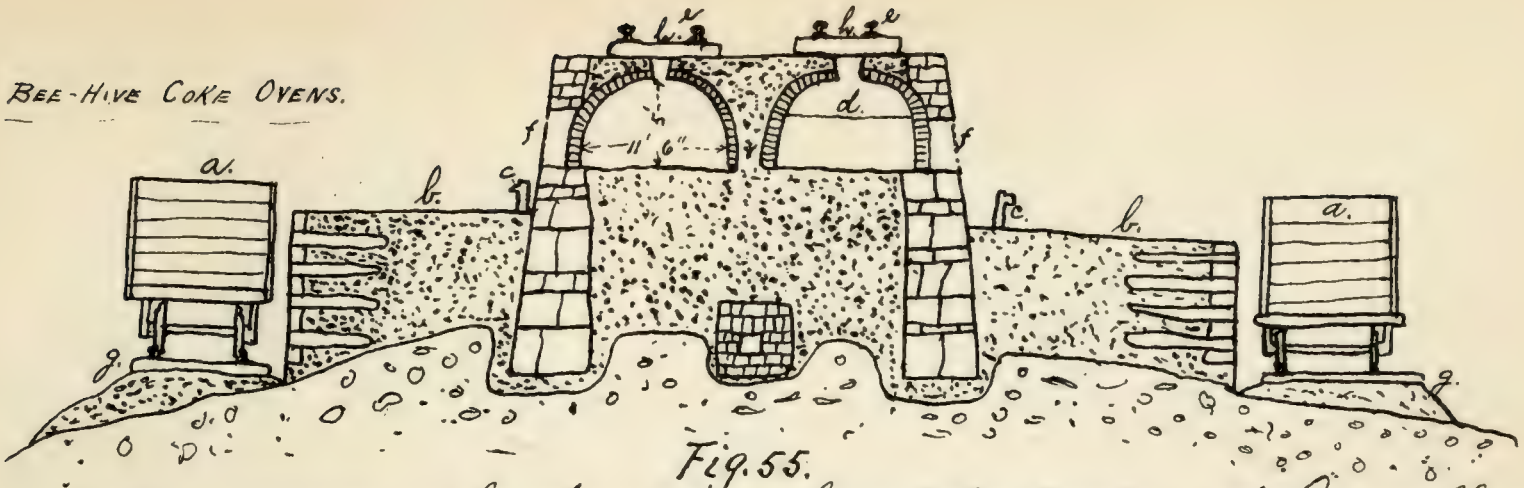


Fig. 55.

Section across a bank of Bee-hive Coke Ovens at Connellesville, Pa., (from Census 1885 by Weeks.)

a. – shipping car.
b. – coke wharf.
c. – water hose.
d. – coal level in ovens.
e. – coal track.
f. – draft, and discharging door.
g. shipping track.
h. coal feed door.

The ovens are round and are placed in double rows of from 100 feet to ¼ mile in length.

Coke made in a bee-hive oven from a suitable coal is strong, silvery, porous, has metallic ring and appearance, and columnar structure. Good coke is free from sulphur marks and pieces of slate. Coke unites more good qualities than any other blast furnace fuel. In A. I. M. E. XII, p. 212 an analysis of Connellesville coke gives:- Moisture .30%, volatile matter .46%, fixed carbon 89.57%, ash 9.11%, sulphur .82%, phosphorous .014% Hardness and well developed cell structure are most important.

The Belgian ovens, which save the tar and by-products by retort distillation, make their coke at a lower heat, make a higher per cent. from the coal, but the coke is more soft and friable, and of less value as a blast furnace fuel.

At the present time much coke is made in Germany in retorts. Where by-products are to be saved the Otto-Hoffman oven is considered the best one; if it is desired to erect ovens without the saving of by-products, the Otto-Coppee ovens are recommended (see, "Coking with Recovery of By-Products," Iron Age, Sept. 6, '94.) (for drawings of "Otto-Hoffman oven, see "Stahl und Eisen," '92, (912-965) plates XVI, XVII.)

Bee-hive Oven Coke.

Pa. Geological Survey, vol. L, p. 117, gives the following table for bee-hive coke.

100 bushels coal @ 76 lbs. = 3.39 gross tons coal fed.
120 " coke " 40 " = 2.14 " " coke yielded.
yield = 63% of coke – loss = 37% or 1.6 tons coal gives 1 ton coke.

The 48 hour charge is 3' deep, 72 hour charge is 4'6" deep.

Belgian ovens yield 70% coke with 30% loss. In Pa. Geol. Survey, vol. L, p. 126, the cost of coke producing is stated as $2.20

Coke (con.)

per ton in Bee-hive, and $1.87 per ton in Belgian ovens. According to "Iron Age". Sept. 6-94, the yield of coke in an Otto-Hoffman coke plant varies from 74 to 76%; the coal is poor. The charge per oven is 6.76 net tons of dry coal; average running time is 40.8 hours. The standard dimensions of these ovens in Westphalia are 21.5 inches at small end, 25.3 inches at large end. They are 32.8 feet long and 5.7 feet high.

The ash in coke can be much reduced by crushing and jigging previous to coking the coal; in this way lumps of slate and pyrites are eliminated. In most instances however this costs more than it saves.

Anthracite.

Anthracite as a blast furnace fuel is inclined to decrepitate and give trouble from its fineness. Its density is so great that it only slowly burns to CO at the tuyeres, and hence furnaces using anthracite can not be driven like a coke furnace. If ¼ coke is used with the anthracite it helps greatly to keep combustion down to CO at the tuyeres, and increases therefore the capacity per day of the furnace. From 6000 to 8000 cu. ft. of air per minute is about all an anthracite furnace can take; if it is driven beyond that, white iron and black cinder will be probable result. A coke furnace can be driven beyond 30,000 cu. ft. per minute.

Bituminous Coal.

Bituminous coal is not much used in the blast furnace as it cakes, and absorbs heat for distillation of volatile constituents.

3. Management.

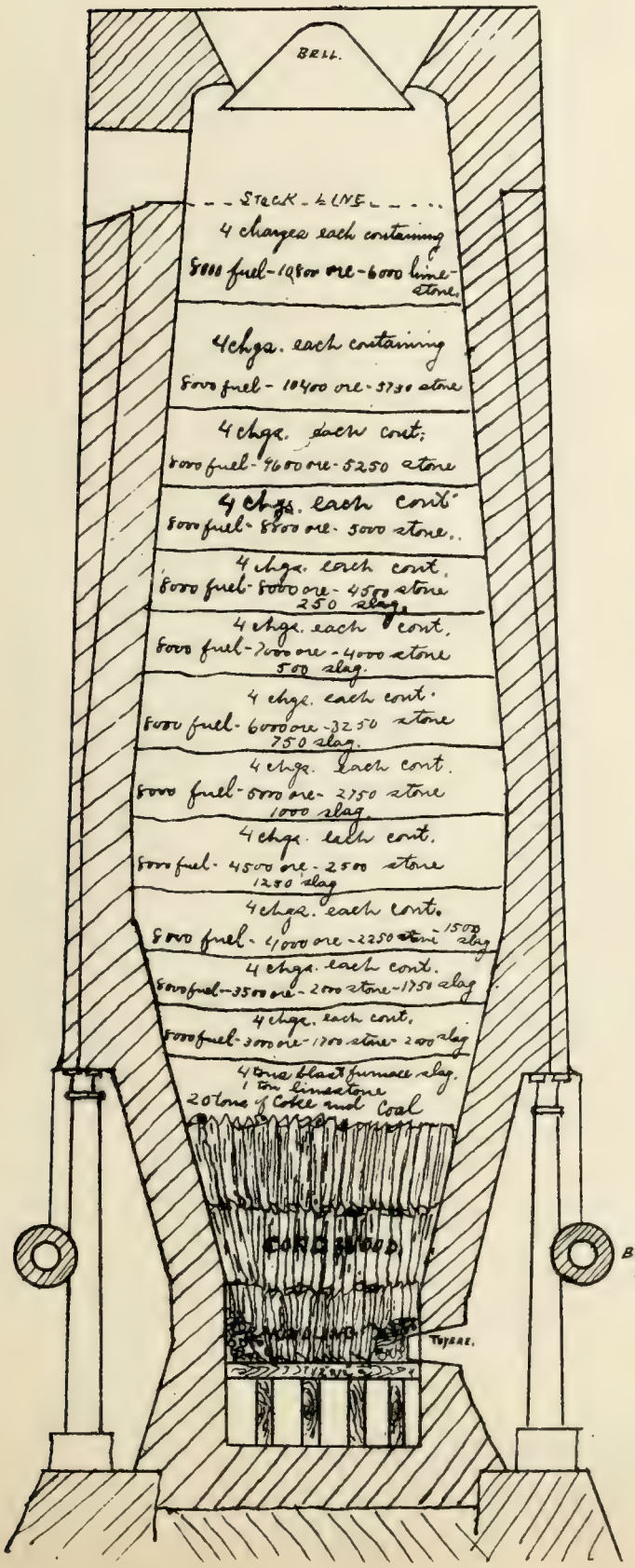
Regular Running.

Ore, flux, and fuel are brought in barrows ("buggies") from the bins in the stock-house or stock-yard to the scales. Here they are quickly made up to a definite weight, calculated by the superintendent, and wheeled onto the elevator. The "top-fillers" take them from the elevator to the hopper and dump them into it. When a certain number of barrows of each have been dumped into the hopper, the bell is lowered and the charge falls into the furnace; then the bell is raised. It is usual to "drop" the fuel charge by itself, and then the charge of ore and limestone together. The charging is regulated so that the level of the stock in the furnace is kept constant; that is, the furnace is kept full. The level is determined by lowering an iron rod through a hole in the bell until it strikes the charge. The temperature of

Regular Running (con.)

the blast must be kept nearly constant, and the pressure watched, as a rise in pressure indicates trouble. If the blast from the stoves becomes too hot for the best working of the furnace it can be immediately cooled down by taking part of the blast directly from the cold-blast pipe. Cooling water must be kept constantly running through the blocks, tuyeres, jackets, etc. Slag is run off either continuously or at short intervals. The iron is tapped regularly into a runner through which it flows either into the moulds of the pig-bed, or else into the direct-metal ladles. When solid, the pigs are broken apart, cooled, and removed to the pig-yard and stacked.

Fig. 56.


BELL.
STOCK-LINE
4 charges each containing
8000 fuel - 10800 ore - 6000 limestone.
4 chgs. each containing
8000 fuel - 10400 ore - 5750 stone
4 chgs. each cont.
8000 fuel - 9600 ore - 5250 stone
4 chgs. each cont.
8000 fuel - 8800 ore - 5000 stone
4 chgs. each cont.
8000 fuel - 8000 ore - 4550 stone
250 slag.
4 chgs. each cont.
8000 fuel - 7000 ore - 4000 stone
500 slag.
4 chgs. each cont.
8000 fuel - 6000 ore - 3250 stone
750 slag.
4 chgs. each cont.
8000 fuel - 5000 ore - 2750 stone
1000 slag.
4 chgs. each cont.
8000 fuel - 4500 ore - 2500 stone
1250 slag
4 chgs. each cont.
8000 fuel - 4000 ore - 2250 stone 1500 slag
4 chgs. each cont.
8000 fuel - 3500 ore - 2000 stone - 1750 slag
4 chgs. each cont.
8000 fuel - 3000 ore - 1700 stone - 2000 slag
4 tons blast furnace slag.
1 ton limestone
20 tons of Coke and Coal
CORD WOOD.
BUSTLE PIPE.
TUYERE.

Blowing In.

After a furnace has been built or relined it is thoroughly dried, and then filled with fuel, ore and flux. The method of filling a furnace for blowing in will be best understood by referring to the accompanying sketch (fig. 56). [This sketch is from A. I. M. E. XVIII, p. 379, which is a description of the blowing in of Durham furnace, Riegelsville, Pa.] In this drawing is shown a scaffold reaching to the tuyere level. This is often omitted, the wood being placed directly on the hearth. In this case (see fig. 56) the amount of ore increases at every fourth charge until the regular burden is reached. This furnace was lighted at the tuyeres and allowed to burn for 29 hours before the blast was put on. (Half an hour after lighting a slight draft was given for two hours by running the blowing engine very slowly.)

Partial Record of Blowing in Durham Furnace.

Furnace lighted	4.30 P.m.	March 23, 1889.				
Blast on	9.30 "	" 24 "	- 29 hours after lighting			
First cinder	1.30 "	" 25 "	- 45 "	"	"	
First iron	8.30 A.m.	" 26 "	- 64 "	"	"	

Fuel = $\frac{1}{4}$ coke, $\frac{3}{4}$ anthracite.

(R.H.S.)

Blowing in "D" Furnace, Maryland Steel Co., Sparrows Point, Md.

No timber scaffold was built in this furnace, but the crucible was packed solid with cord wood up to the tuyere level. A layer of kindlings, with shavings in front of each tuyere was then put in, and cord-wood piled above that. The wood was laid flat instead of on end. Above this wood came a blank charge of coke and then charges with increasing amounts of ore till the regular charge was reached. No slag was used. Fuel all coke.

Furnace was lighted by putting hot-blast (680° F. - 0 lbs pressure 10,680 cu. ft. air per min.) through tuyeres. Tap-hole left open to give draft down through crucible as well as up through furnace.

				Hours after lighting.
D Furnace lighted by hot-blast	7.20 P.m.	Apr. 14, 1893		
Tap-hole shut in	10.45 "	" " "		
First cinder	8.40 A.m.	" 15 "	-	13 hrs 20 mins.
First iron	11.55 "	" 15 "	-	16 " 35 "

A furnace may have to shut down temporarily on account of a falling market, a flood of water, or a strike. In the last two instances the furnace must be banked at a moments notice, and the only thing that can done is to tap the metal out as clean as possible, shut off the blast, and close up the furnace as much as possible so as to prevent any draft up through the stock. The tuyeres can be quickly "blanked" by ramming in clay-balls and brick-bats. The blast in this case should be resumed very soon, in two or three weeks at the longest. In the former case where there is time to plan for the shutting down, a large blank of coke is charged, and this is followed by charges of ½ quantity ore, then ⅔, and finally by full ore charges. When the blank reaches the tuyeres the blast is shut off. The bell is sealed with fine ore. The cooling water is gradually decreased. Where the furnace has no iron shell, the whole stack is white-washed, or clay-washed. ("Stahl und Eisen", 1889, p. 991.)

The following data from the record of a furnace (85' high) that was banked in July 1893, will give an idea of how much stock was required:— a "blank" of 60 charges, each containing 6720 lbs. of coke and 680 lbs. of limestone was put in, and on top of that 1 charge containing 6720 lbs. coke, 1120 lbs. limestone and 3360 lbs. of ore. Total amount of coke = 183 long tons. The furnace was easily started up again after being banked 38 days.

Blowing Down.

When a furnace is to be blown out for repairs or any other cause, ore charges are stopped, and a layer of coke, with a little limestone to flux its ash, of sufficient depth to maintain a reducing atmosphere to the last, is charged. Tapping of pig and slag is kept up as long as anything will come. To keep the top of the furnace cool a spray of water may be run in through a hole in the bell or in the charging floor (see A. I. M. E. vol. XIII, p. 670). In vol. VI, A. I. M. E. p. 169, is a description of blowing out a furnace by using nothing but limestone on top of the last ore charge. "When the blast was taken off there was nothing but lime above the tuyeres, and an insignificant salamander below. The lime, amounting to about 1400 bushels, was washed out with water in 15 hours after the blast was stopped. By means of lime the pressure was kept up to the last, making it possible to burn up nearly all the coal."

4. Chemistry and Heat of Blast Furnace.

(This section is based on the works of Sir Lowthian Bell).

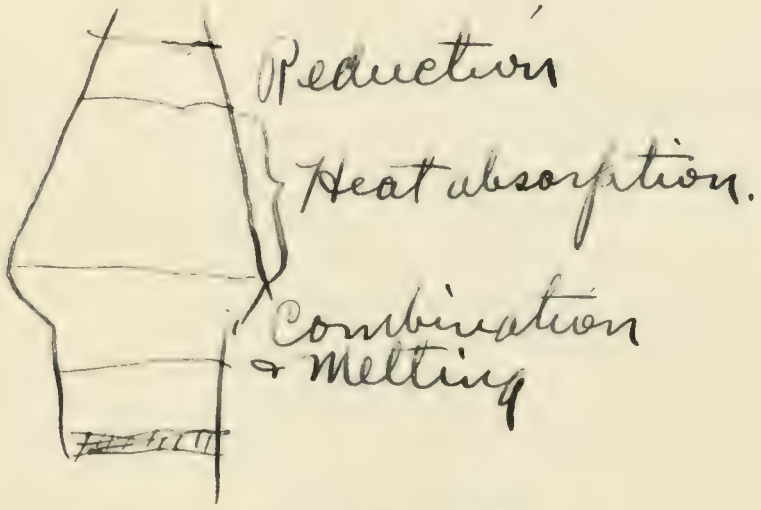
In the blast furnace we have a descending column of solids acted upon by an ascending column of gases, at a constantly increasing temperature.

The principal reducing agent in the blast furnace gases

Objects

1 - reduce oxides of to metals + elements
2 - drive CO_2 from $CaCO_3$
3 - combine Fe, C, Si, Mn. to pig.
4 - " SiO_2, CaO, Al_2O_3 to a slag
5 - burn coke wholly at tuyere to CO
" CO to CO_2 near top of furnace.

Fe_2O_3 reduced to Fe by CO best at low temps. (38)
pig melted best at high temps.
Slag formed " " " "



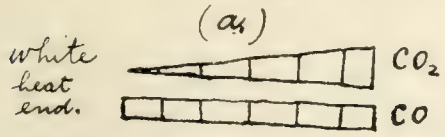
Four ruling temperatures.

400° F., CO begins to reduce Fe_2O_3
750 F., C " " " Fe_2O_3
800 F, CO_2 oxidizes Fe
1500 F, " " Coke or Carbon.

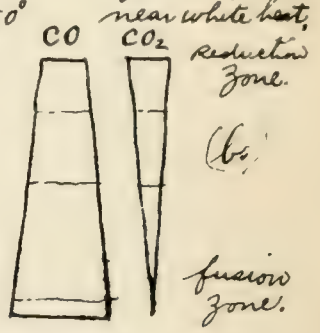
as CO. This is mixed with CO_2, an oxidizing agent. At the temperature of the waste gases, a neutral mixture is 2 CO_2 to 1 CO, but as the temperature increases the amount of CO_2 necessary to neutralize CO decreases rapidly.

1.5 volumes CO_2 stop 1 volume CO from reducing Fe_2O_3 to below Fe_3O at 850° F. low red heat
0.47 " CO_2 " 1 " CO " " " " " " " 1500° full " "
0.11 " CO_2 " 1 " CO " " " " " " " 1850° near white heat.

(a.)



Sketch (a.) shows the relative amounts of CO and CO_2 necessary to make a neutral mixture.



Sketch (b.) shows roughly the relative amounts of CO and CO_2 in the blast furnace.

CN and H are also reducing agents but are present in small quantities only.

Since raw ore is calcined in the upper part of the blast furnace (see "Roasting," p.7), reactions for calcined ore only will be given.

The first action that takes place when ore is charged into the furnace, is the cooling down of the escaping gases, and the pre-heating of the ore. When the ore is heated to about 400° F. (204° C.) CO begins to reduce Fe_2O_3 to sub-oxide and metal.

A. (1.) $Fe_2O_3 + CO = 2FeO + CO_2$. (2.) $Fe_2O_3 + 3CO = 2Fe + 3CO_2$

B. Oxidation of metal and lower oxide to higher oxide by CO_2.
{un-doing the work of reduction.} (3.) $x Fe + y CO_2 = Fe_xO_y + y CO$. (4.) $Fe_xO_{y-1} + CO_2 = Fe_xO_y + CO$.

C. Reduction of CO to C. Deposition of Carbon.
(5.) $x Fe + y CO = Fe_xO_y + y C$. (6.) $Fe_xO_{y-1} + CO = Fe_xO_y + C$.

D. Reaction of reduced carbon on iron oxide forming CO_2.
(7.) $2 Fe_xO_y + C = CO_2 + 2 Fe_xO_{y-1}$ (8.) $2 Fe_xO_y + yC = y CO_2 + 2x Fe$.

E. Reaction of CO_2 on reduced carbon.
(9.) $CO_2 + C = 2 CO$.

At any given point in the furnace all these chemical tendencies are at work simultaneously. The action actually taking place at this point is that due to the single resultant of the various forces involved, — namely, the iron-reducing tendencies (A.) and (D.), the iron-oxidizing (B.) and (C.), the carbon-reducing (C.), and the carbon-oxidizing (D.) and (E.) tendencies. In the zone of reduction (A, fig. 59.), tendencies (A) and (D) jointly are stronger than (B.) and (C.) jointly, and consequently rapid reduction of Fe_2O_3 takes place. Tendency (C.) is here stronger than (D.) and (E.), and carbon deposition takes place to a large extent. Limestone, ($CaCO_3$), is here nearly completely changed to CaO. In the heat intercepting zone (B. fig. 59.) the various tendencies are so nearly balanced that reduction goes on only languidly, the chief effect being increase of temperature.

In the zone of fusion (C, fig. 59.) the reduction of the small residue of iron oxide takes place chiefly through the agency of the cyanides formed near the tuyeres. A portion of the metalloids, Si, P, and S, are reduced, and in company with a certain quantity of carbon combine with the metal; over 90% of the P passes into the iron. The lime and the non-metallic constituents of the ore fuse and form slag. (These equations are from "Introduction to Study of Metallurgy" by Roberts-Austen, 1894, page 243)

Sulphur, whether present as FeS_2 or $CaSO_4$, when the slag is strongly basic, goes into the slag to the extent of 95 per cent., as CaS.

Some MnO_2 and SiO_2 are reduced to Mn and Si, which combine with the iron.

H_2O entering with the blast is decomposed. $H_2O = 2H+O$.

Coke burns at the tuyeres to CO. $C+O = CO$.

The sketch below (fig. 57) is a graphical representation of the chemical changes which take place in the iron blast-furnace. Horizontal widths represent the proportions roughly. Solids move downwards, gases upwards.

A. Last of the coke is burned. The first CO and Cyanogen are produced.

B. First of the coke burns. Generation of CO and CN completed.

C. Melting begins. Gases remain same as last.

D. Last $CaCO_3$ decomposed. CO_2 appears in the gases.

E. First $CaCO_3$ decomposed. CO_2 increasing, CO diminishing.

F. Last of Fe_2O_3 reduced. First Fe appears, also first deposited C.

G. First Fe_2O_3 reduced. CO_2 at a maximum, heat at a minimum.

In zone G.F. Fe_2O_3 is reduced to FeO

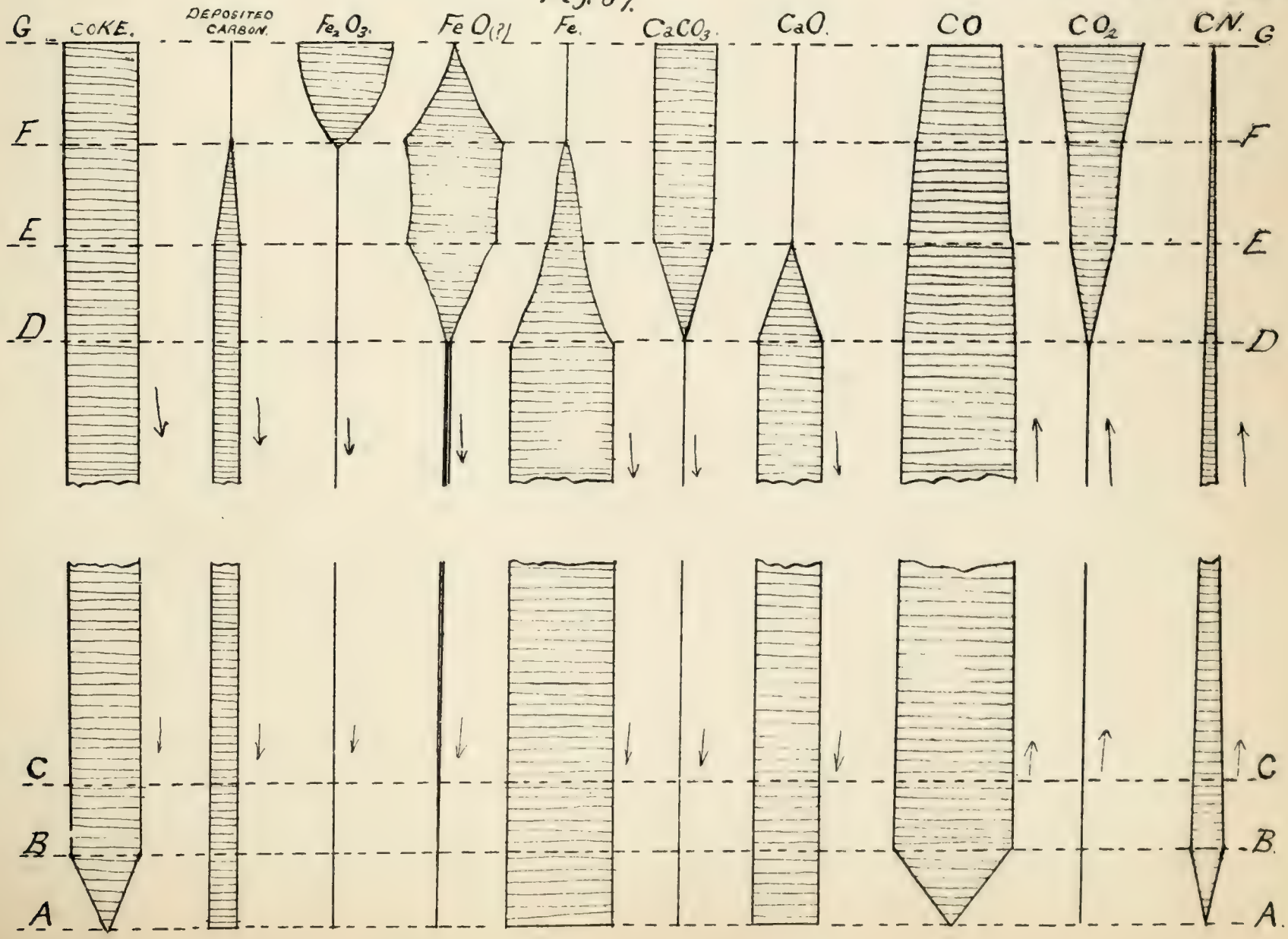
" " F.E. Reduction of FeO to Fe hindered by CO_2 from $CaCO_3$.

" " E.D. Reduction " " " " rapid. $CaCO_3$ decomposed.

" " D.B. The bulk of the heat from combustion at tuyeres is absorbed by the charge

" " B.A. Coke is burned to CO.

Fig. 57.



Estimate of the Quantity of Heat required in Iron Smelting.

The following calculations are from Bell's "Chemical Phenomena of Iron Smelting" (1872) p. 148, and "J. of I. and S.I." vol. II, 1893, p. 219.

"The heat required consists of that really absorbed by each stage of the operation, and of loss. The quantity of heat required varies to some extent, according to circumstances; for illustration Bell has selected an example of a furnace having a capacity of 11,500 cu. ft., smelting calcined Cleveland (England) ironstone, yielding 41% of pig-iron (about #3 in quality), and using 13.66 cwts. of limestone per ton of metal. Temperature of the blast was 485°C (905°F) and that of escaping gases 332°C (630°F.)"

"The sources of heat absorption will be divided under two classes, viz., those really required for the process, comprising chemical action and fusion, — and those which may be regarded as actual, although to a great extent, unavoidable loss, so far as the operation in the furnace itself is concerned. The calculation is based on the production of 20 kilograms of pig iron of the following composition:-

Fe	=	18.60	kilograms in 20 kilograms of pig
P	=	0.30	" " " " " "
S	=	0.02	" " " " " " "
Si	=	0.48	" " " " " " "
C	=	0.60	" " " " " " "
		20.00	"

Appropriation of Heat per 20 units of Pig Iron in Furnace 80 feet high, blown with hot air.

Class I.

Heat required for Chemical action and Fusion.

	Units		Calories.		Calories	=	Units Coke at 3,994 cals.
(1.) Evaporation of water in coke	.58	x	640	=	372		.093
(2.) Reduction of iron peroxide	18.6	x	1,780	=	33,108		8.277
(3.) Carbon impregnation	.6	x	2,400	=	1,440		.360
(4.) Expulsion of CO_2 from limestone.	13.66	x	370	=	5,054		1.263
(5.) Decomposition of CO_2 by carbon. (C.)	1.64	x	3,200	=	5,248		1.312
(6.) Decomposition of hygrometric water. (H.) [in blast]	.08	x	34,000	=	2,720		.680
(7.) Metalloids in pig iron reduced (approx.)					4,174		1.043
(8.) Fusion of pig iron.	20.00	x	330	=	6,600		1.650
(9.) Fusion of slag.	30.00	x	550	=	16,500		4.180

Class II.

Losses.

(10.) *Loss by radiation, convection, etc.	5,476	1.369
(11.) Carried off in escaping gases	8,451	2.093
	89,143	22.320

*Transmission through walls of furnace carried off by waste water from tuyeres bosh blocks, etc.)

Heat (conv.)

Particulars of Heat evolved in a furnace 80 feet high, blown with hot air.

Coke consumed per 20 kilograms of pig iron, 22.32 kilograms, less ash, etc (1.92 kilo.) equal to } 20.4 kilo. of C.
Less carbon in 13.66 kilos. of limestone carrying } 1.64 " "
of carbon in coke
Leaving to be burnt at the tuyeres (available C.) = 18.76 " " "

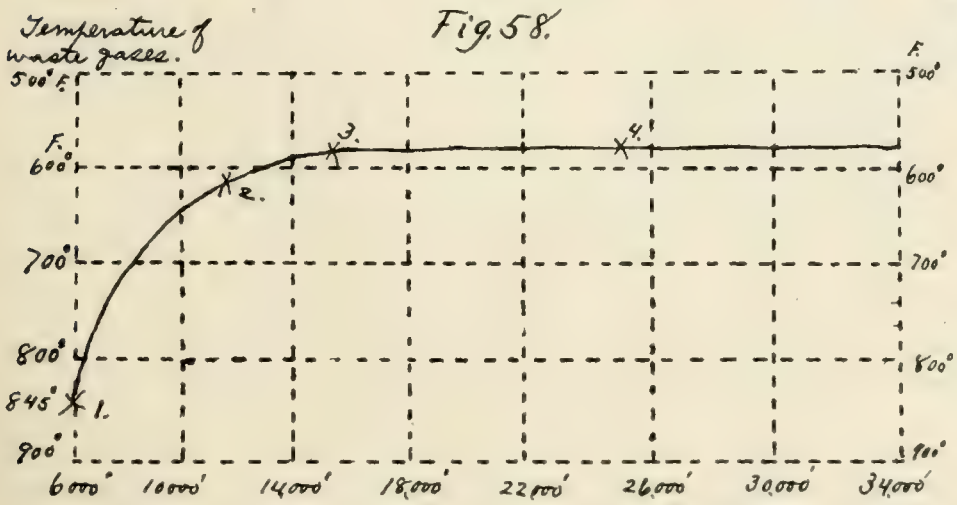
(12.)	18.76 kilos. of carbon burnt to carbon oxide	× 2,400	= 45,024	calc.
(13.)	5.75 " " this CO burned to CO_2	× 5,600	= 32,200	"
			77,224	"
(14.)	Heat in blast (103.74 kilos. × 485°C × .237 S. heat)		= 11,919	"
			89,143	"

Value of one unit of coke, $\frac{89,143}{22.32}$ = 3,994 calories.

In another furnace of the Clarence Works (England.), where the blast was heated to about 1300° F, each unit of coke afforded 4,431 calories. Total heat generated for 20 kilos. of pig iron amounted to 88,577 calories, obtained from 19.99 kilos (units) of coke. The capacity of the furnace was 24,800 cu. ft. (see Journ. Iron & Steel Inst. No. II, 1893 p. 229.)

The loss in sensible heat of the waste gases (11.) may be reduced by increasing the height of the furnace, thus furnishing greater surface of ore for absorbing heat, i.e., increases the extent of the zone of heat interception (see figs. 58 and 60). But a limit in the economy of extending this zone is reached, and above a certain height there is no gain. This is shown by the curve in fig. 58 (Bell's "Principles of Mfg of Iron and Steel. p. 75). This limit is reached because the combustion of CO to CO_2 (13.) evolves more heat than the reduction of Fe_2O_3 (2.) absorbs. This reduction begins at 400° F. (see reactions page 38.)

Fig. 58.



The determined points in fig. 58 are

× 1.	Clarence furn.	- 6,012	cu. ft. capac.
× 2.	"	" 11,578	" " "
× 3.	"	" 15,363	" " "
× 4.	"	" 25,497	" " "

The loss of heat absorbed by the decomposition of hygrometric water (moisture in the blast) is here given as 2,700 calories equal to .68 coke units per 20 units of pig iron produced (6.), but this amount varies with the relative humidity of the atmosphere.

On account of the humidity of the atmosphere several

thousand pounds of water are carried into the furnace every 24 hours. The amount will be less in the winter months, consequently the fuel consumption should be less in the dryer winter months than in the summer. Some recent investigations (incomplete.) showed that in the blast of a furnace blown with about 30,000 cu. ft. air per minute was carried into the furnace about 24000 lbs. of water in 24 hours (daily av. for Oct. '93) while in Nov. '93 the average was about 19,400 lbs. of water per 24 hours; in December the amount of water was about 13,200 lbs. per 24 hours. The records of four furnaces (1889-1894) showed that the fuel consumption ("fuel ratio") tended to decrease during the winter months, and in some cases the decrease was marked. (R.H.S)

Fig. 59

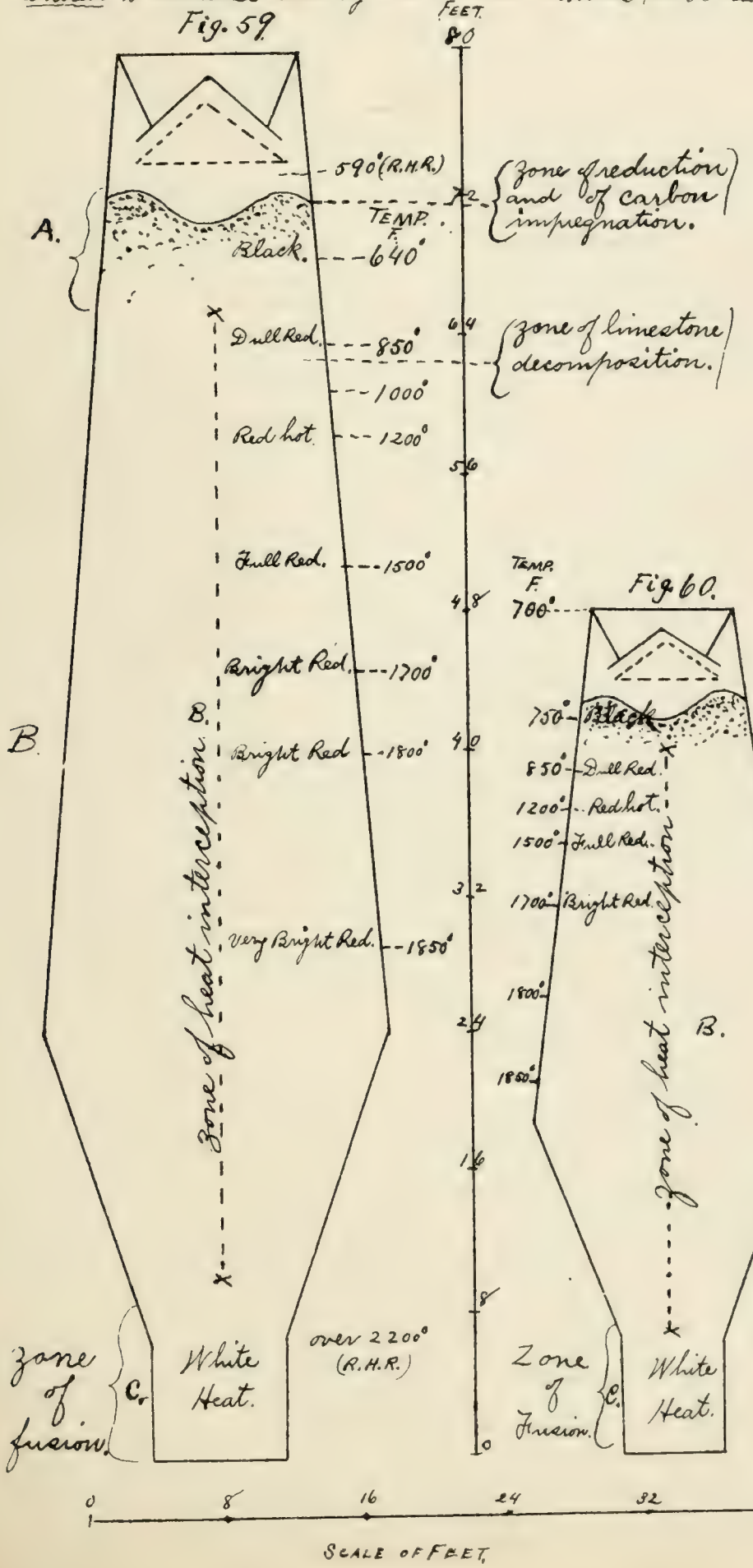
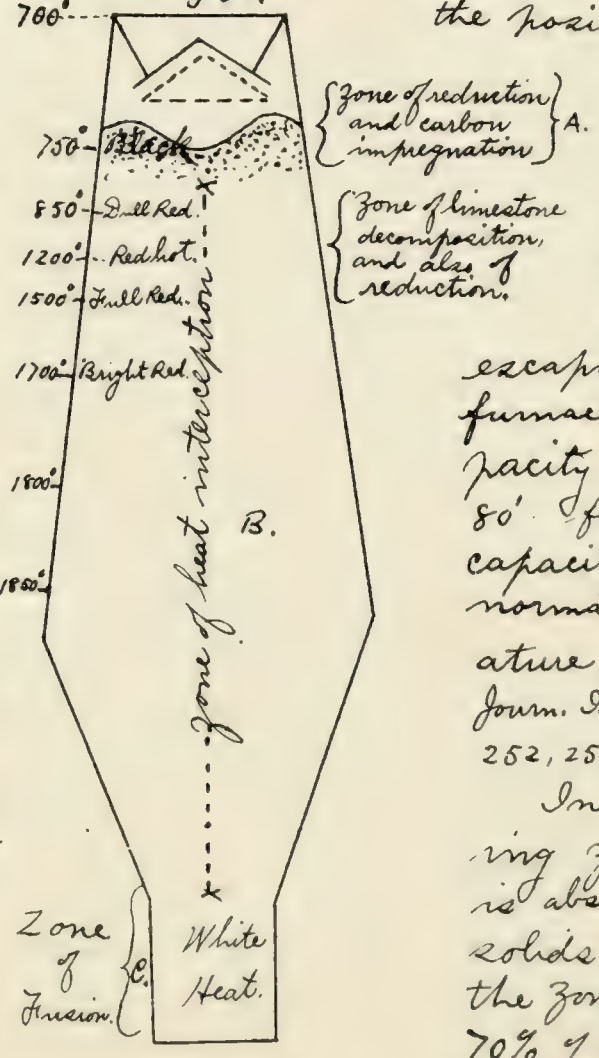


Fig. 60.



The three zones of the interior of the blast furnace are shown in figs. 59 and 60.

The "upper or reducing zone", (A.), is the part in which most of the chemical action (p. 38) takes place. By the reactions in this "upper combustion zone" fresh heat is generated and the temperature of the escaping gases is raised, any further addition to the height of the furnace, with a view to cooling down the waste gases, raises the position of this zone and leaves the temperature of the gases carried upward almost unchanged. Sir Lowthian Bell gives 475° F as the average temperature of escaping gases from an 80' furnace of 11,500 cu. ft. capacity, and 475.5° F. for an 80' furnace of 21,600 cu. ft. capacity. He calls 782° F. the normal limit of the temperature of escaping gases. (see Journ. I. and S. Inst. 1893, II, p. 252, 253)

In the heat-intercepting zone (B. fig 59-60) heat is absorbed by the descending solids and carried down into the zone of fusion (C.) About 70% of the heat in the fusion zone is brought down from the heat intercepting zone. (Bell.)

Theory of the Hot Blast.

In blowing a furnace with cold blast such a large quantity of fuel is needed at the tuyeres to obtain the necessary heat for fusion of iron and slag, that enormous amounts of gases are produced. In a low furnace most of this sensitive heat was wasted in the escaping gases. When hot blast was introduced into low furnaces a great saving in fuel was obtained, because much of the heat required in the hearth was furnished by the hot blast. Later when high furnaces were built, a further great saving in fuel was obtained, because much of the sensitive heat passing off in the waste gases from the low furnaces, was, in the high furnaces, absorbed in the enlarged zone of heat interception, and consequently less fuel was required. With the reduction in the amount of fuel comes also the reduction in the amounts of flux and blast required. This great saving in fuel may be seen from these figures:-

furnace	42	feet	high	-	cold blast	-	6000 lbs. coke per 2000 lbs iron.
"	48	"	"		hot	"	2892 " " " 2000 " "
"	70	"	"		cold	"	3800 " " " 2000 " "
"	80	"	"		hot	"	1999 " " " 2000 " "

(Bell: J. I. & S. I. 1893, II, p. 221)

In American furnaces the fuel consumption has been brought down as low as 1680 lbs. of coke per ton of iron. An average of four furnaces for one month was 1834 lbs. of coke per ton of iron. (A. I. M. E. XXIII, 373.) A furnace of the Union plant of the Illinois Steel Co. has made over 5800 tons of (Bessemer) pig iron in one month with a fuel consumption of 1680 lbs. of coke per (long) ton of pig. (A. I. M. E. XIX, 973.)

The Slag.

The earthy materials and the sulphur of the ore and fuel pass off in the slag. Most of the sulphur is eliminated in this way, but very little of the Phosphorus is.

In running with a high lime slag to avoid both high sulphur and high silicon in the pig, there is danger of having a "lime stick", that is, the slag will be so "limey" that it won't run well but will stick. To avoid this a higher percentage of alumina is used.

(J. W. C.)

52%	$CaO + MgO$	Good slag.
18%	Al_2O_3	
30%	SiO_2	

52%	$CaO + MgO$.	Bad Slag.
10%	Al_2O_3	
38%	SiO_2	

Slag Calculation.

Indicated graphically on page 45.

We must first obtain the analyses of our ores, flux, and fuel. We will next subtract an amount of SiO_2 from the percentage of that compound, which will yield the desired amount of Si, say 1.5%, for the iron at 93% in the pig. That is to say 93 : 1.5 = % of Fe in iron ore : % Si to be subtracted = a, and $Si : SiO_2$ = a : amount SiO_2 to be subtracted. Now, having made these subtractions, we tabulate the corrected analyses and get:-

N.B. ("CaO" in these calculations includes CaO and MgO)

	Fe. %	Fe_2O_3. %	CaO. MgO %	Al_2O_3. %	SiO_2. %	H_2O.	Total
A. ore with SiO_2 in excess over Al_2O_3	55.	78.57 %	6. %	2. %	12. %		98.57 %
B. " " Al_2O_3 " " " SiO_2	40.	57.14	5.	12.	15.	8.	97.14
C. Limestone { CaO " " " SiO_2 }			51.	1.	4.		56.
{ SiO_2 " " " Al_2O_3 }							
D. Coke Al_2O_3 " " " SiO_2			2.	3.	5.		10.
E. Slag we desire to make			52.	16.	32.		100.

The excess of SiO_2 for example referred to in this table means that the SiO_2 bears a higher ratio to the Al_2O_3 in said material than it does in the slag, E, we are aiming for. So also with the other excesses.

We will now bring together opposite excesses so that they shall neutralize each other. The resulting mixture will contain two or more of its ingredients, SiO_2, Al_2O_3, and CaO in the proportion proper to the slag. This mixing we will call balancing the one material against the other.

Balance A and B with reference to SiO_2 and Al_2O_3 gives F.
" A " D " " " SiO_2 " Al_2O_3 " G.
" B " C " " " SiO_2 " Al_2O_3 " H.
" F " H " " " SiO_2 " CaO " I.
" G " H " " " SiO_2 " CaO " J.
" I " J to get 1 ton coke for 1 ton of iron " K.

K is the final mixture of siliceous ore, aluminous ore, limestone, and coke which was to be calculated to yield 1.5% Si in the pig, to yield a slag having 32% of SiO_2, 16% of Al_2O_3, 52% of CaO, MgO, and to have 1 ton of coke for 1 ton of iron.

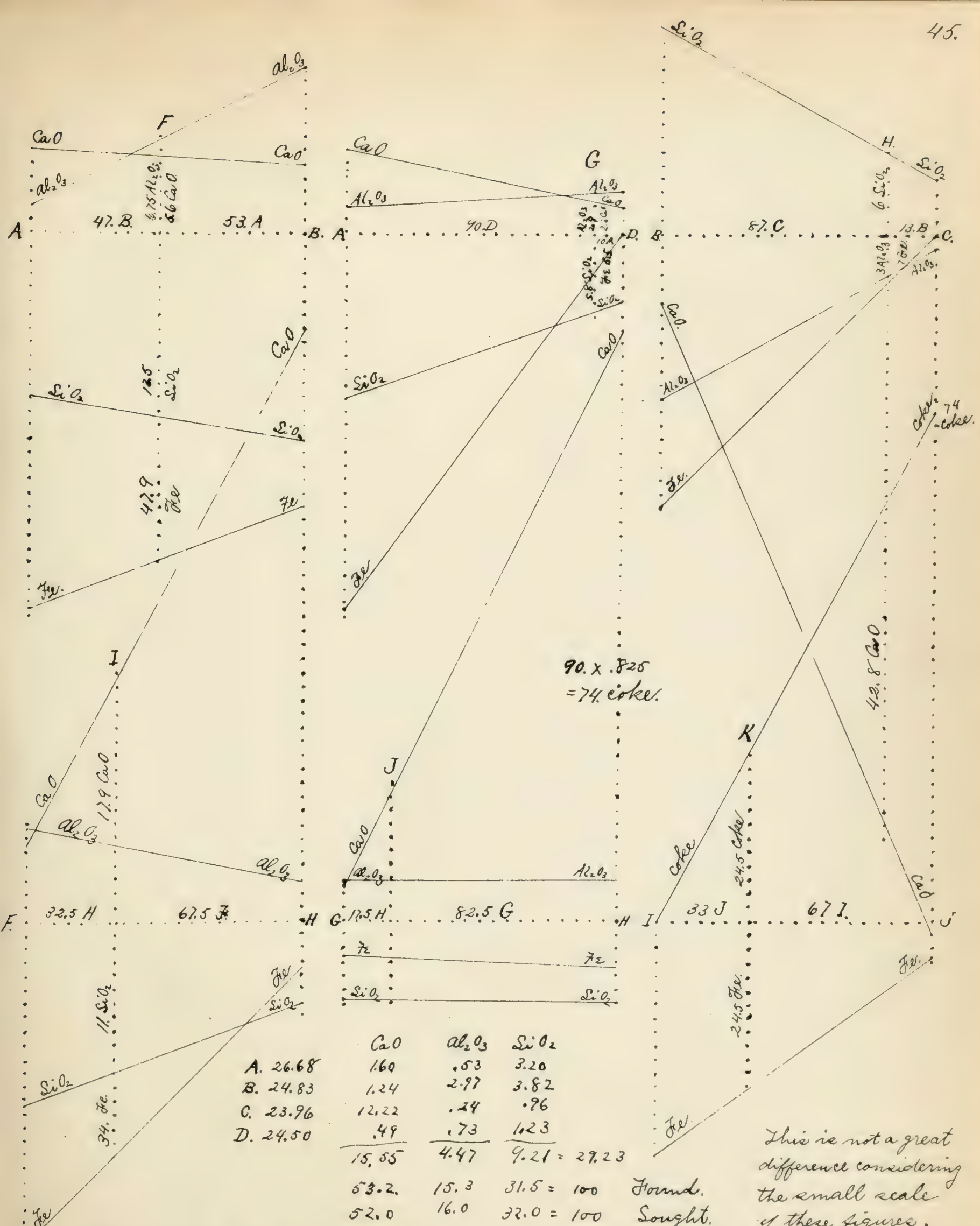
The various steps in this calculation are indicated graphically on the next page and are here summed up.

$K = \begin{cases} .67\ I. \\ .33\ J. \end{cases}$ $I = \begin{cases} .675\ F. \\ .325\ H. \end{cases}$ $J = \begin{cases} 82.5\ G. \\ 17.5\ H. \end{cases}$

$F = \begin{cases} .47\ B. \\ .53\ A. \end{cases}$ $H = \begin{cases} .87\ C. \\ .13\ B. \end{cases}$ $G = \begin{cases} .10\ A. \\ .90\ D. \end{cases}$ $H = \begin{cases} .87\ C \\ .13\ B. \end{cases}$

Multiplying out we have

B_1 = 21.25 aluminous ore.
A_1 = 23.96 siliceous "
C_1 = 18.94 limestone to flux ore B. A.
B_2 = 2.83 ore to flux limestone C.
A_2 = 2.72 ore to flux coke D.
D_1 = 24.50 coke
C_2 = 5.02 limestone to flux coke D.
B_2 = .75 ore to flux limestone C_2
99.97



	CaO	Al_2O_3	SiO_2	
A. 26.68	1.60	.53	3.20	
B. 24.83	1.24	2.97	3.82	
C. 23.96	12.22	.24	.96	
D. 24.50	.49	.73	1.23	
	15.55	4.47	9.21 = 29.23	
	53.2.	15.3	31.5 = 100	Found.
	52.0	16.0	32.0 = 100	Sought.

This is not a great difference considering the small scale of these figures.

The ordinates represent percentages and are measured from the horizontal line. The division of the horizontal line into two parts may be made by a sliding triangle or by trial.

5. Regulating the Blast Furnace.

To control the kinds of pig iron produced by a furnace, we can vary the composition of the slag, and can change the burden. The burden is made heavy by increasing the amount of ore and flux to a charge, and is made light by diminishing the amount of ore and flux to a charge. Starting with a standard slag of, say, 35% SiO_2 and 11% Al_2O_3, and the rest CaO, MgO, and perhaps a little MnO, if we increase the SiO_2, the slag becomes more acid, if we decrease it becomes more basic.

To run for No. 1 Gray iron, run with light burden, hot furnace, and basic slag.

To run for mottled iron, run with heavy burden, cool furnace, and acid slag. Mottled and white pig are rarely sought.

For high silicon iron, run with light burden, hot furnace, and slightly acid slag.

For Spiegel run light burden, hot furnace, high manganese, basic slag. For ferromanganese, like spiegel, only more so.

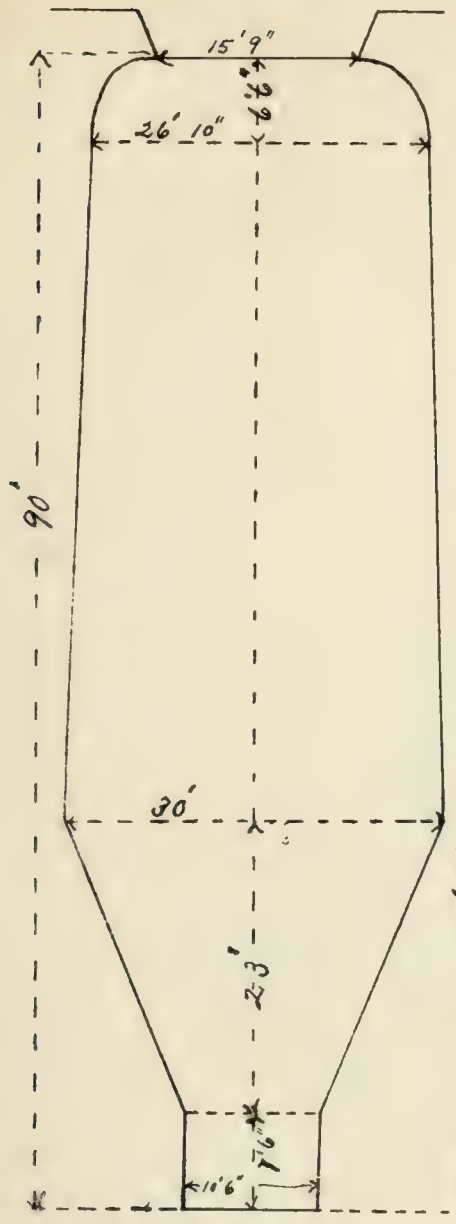
For Bessemer iron in case S is present, run as for No. 1 Gray, only MgO should not be used to replace part of the CaO, as may be done with No. 1 Gray.

To illustrate the above, some slag analyses are here given:-

	SiO_2	Al_2O_3	CaO.	MgO.	MnO.	Fe_2O.	K_2O + Na_2O	CaS.	oxygen ratio.	
Bethlehem Iron Co. Bess. (¼ coke ¾ anthra. cite)	% 34.63	% 9.99	% 28.51	% 25.79	% .16					(corresponds to No.1 × No.2 Foundry)
Steelton, Pa., Bessemer, (fuel all coke)	34.0	12.0	36.0	13.0						then 5% (sum of CaO + MgO = 50 to 52%)
Illinois Steel Co., Bessemer.	48%		52%							
Pueblo Smelting Co., "										
Coke Slags, Ledebur p. 538 (probably No. 1. Gray)										
Königin Marienhütte, Bessemer,	30.20	9.22	39.23	12.31	1.13	.32	2.35	4.79	1.74	
Zeitweg.	33.35	13.21	37.71	7.32	1.43	.21	.53	5.51	.87	
Hoerde, No. 1 Foundry	29.40	11.70	36.11	11.54	.20	.80	—	9.08	.76	
Charcoal Furnace Slags Ledebur p. 536.										
Pfeilhammer	56.10	5.20	21.78	7.21	6.30	2.70	—	—	2.2	Probably No. 3 Foundry.
Edelleen.	46.37	4.30	38.14	7.40	1.86	.95	.43	.07	1.7	
Neuberg	40.95	8.70	30.35	16.32	2.18	.60	.32	—	1.1	
White Iron Slag, Ledebur p. 540.										
Gutehoffnungshütte	39.45	10.70	36.42	2.34	1.95	6.04	1.79	1.05	1.1	
Spiegel Slags, Ledebur.										
Hoerde.	29.00	8.11	43.05	7.14	7.04	.42	—	3.74	0.8	In the Spiegel Mn = 10%
Creuzthal.	32.66	9.49	20.09	8.30	12.78	4.41	—	12.17(?)	1.0	Mn = 11.5%
Ferromanganese Slag, Ledebur p. 544.										
Phoenixhütte (179)	17.88	6.88	27.38	—	44.65	.50	—	—	.45	In ferromanganese Mn = 75%

Furnace Lines.

Fig. 61.



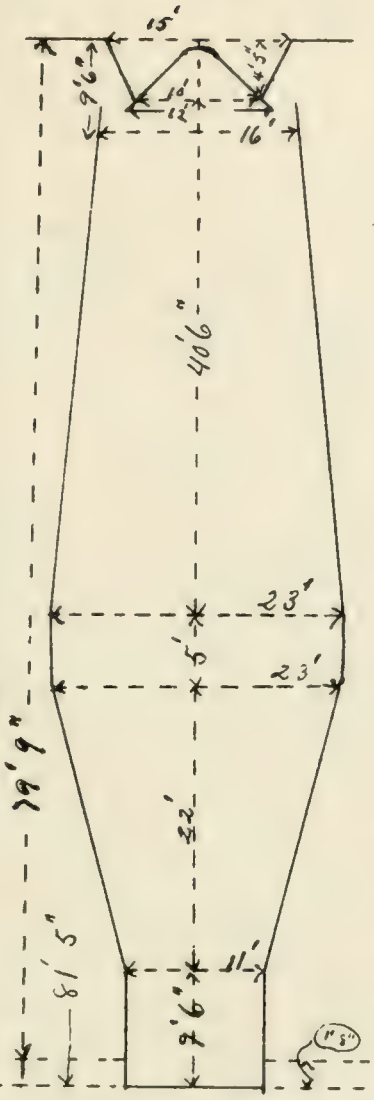
Armesby, England, prior to 1869.

Coke.

Contents = 41,000 cu. ft.

daily product = 79 tons.

Fig. 62.



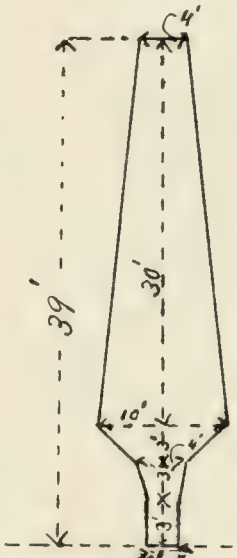
Pittsburgh, Pa., 1890.

Coke.

capac. = 18,200 cu. ft.

daily product = 310 tons.

Fig. 63.



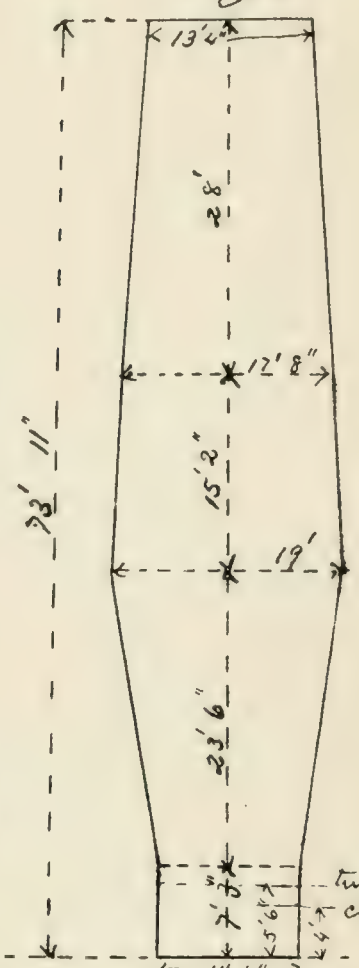
Penna. and Kentucky. 1870 and earlier.

Charcoal.

capac. = 1310 cu. ft.

about 10 tons

Fig. 64.



Pennsylvania. 1889.

$\frac{1}{4}$ coke; $\frac{3}{4}$ anthracite.

about 125 tons.

Fig. 63 shows an early form of furnace, much troubled by slows, high fuel, and low yield. Yield per 1000 cu. ft. capacity was about 7 tons daily. (A. I. M. E. XV. p. 444.)

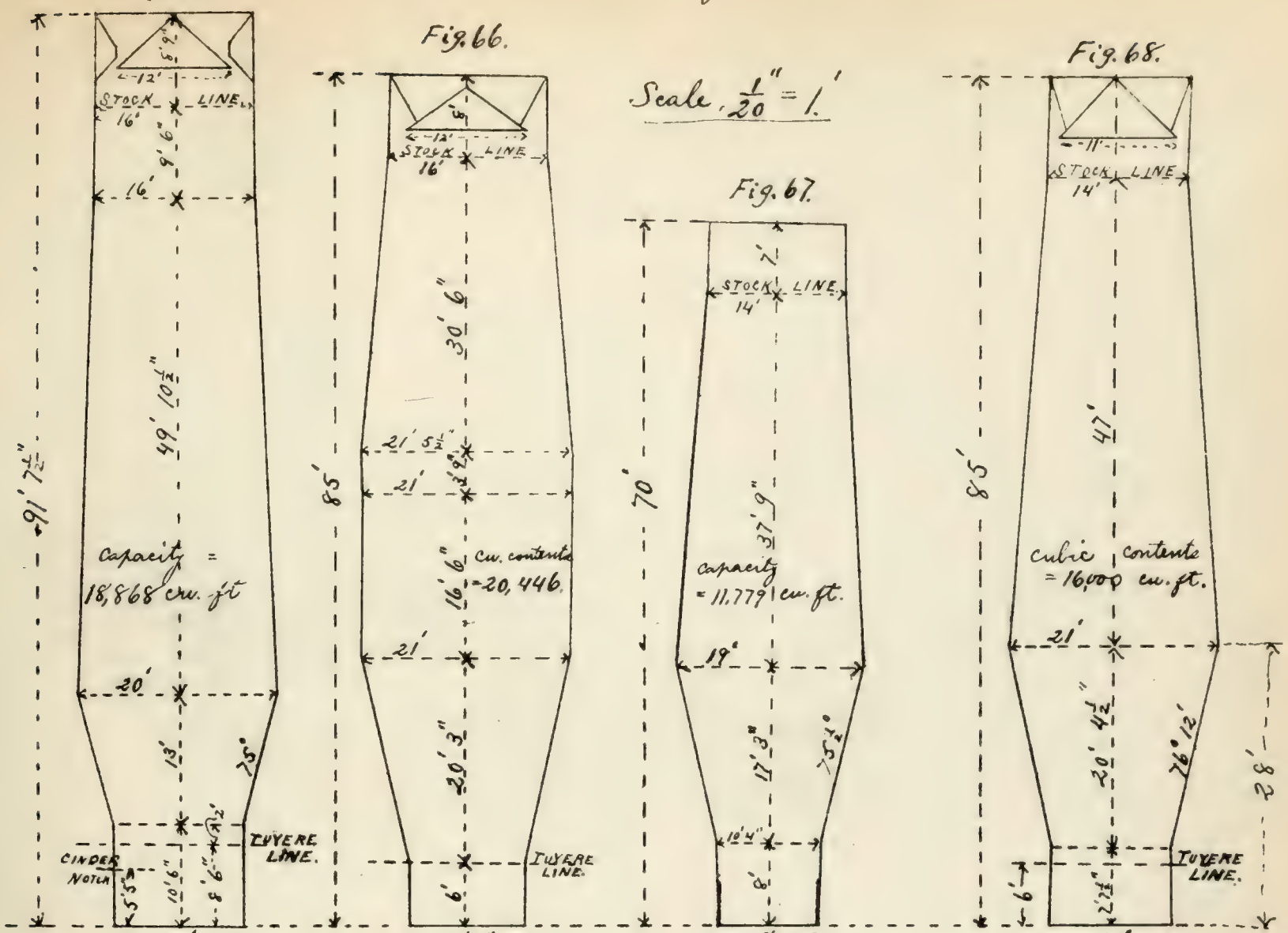
Fig. 61 shows a furnace built as a trial to lower the temperature of waste gases by enormous capacity; it failed to gain anything over fig. 62. Its daily yield was 1.92 tons per 1000 cu. ft. capacity. (see Gedeburn. p. 336, and Bell's Iron & Steel, p. 75.)

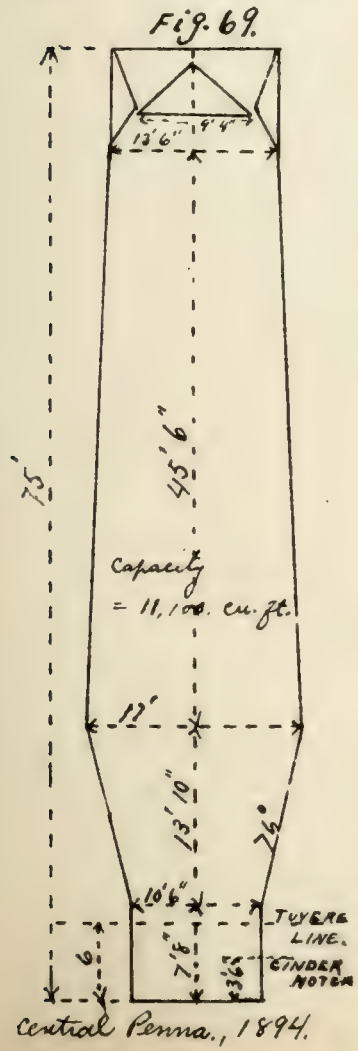
Fig 62. shows what was in 1890 the latest and greatest producer of the world. Yielded 17 tons, per day, per 1000 cu. ft. capacity; coke was 1920 lbs. per ton of pig. It has large crucible, large bell; was driven hard, 25000 cu. ft. of wind per minute, highly heated blast. (Iron, Oct. 24, 1890.)

Fig 64 shows the lines of the Durham (Penna.) furnace (anthracite) blown in March 1889. Largest yield for one week was 915 tons or 130.7 tons per day. (A. I. M. E. XVIII. p. 390.)

Furnace Lines of 1893-1894.

Scale, $\frac{1}{20}$" = 1'





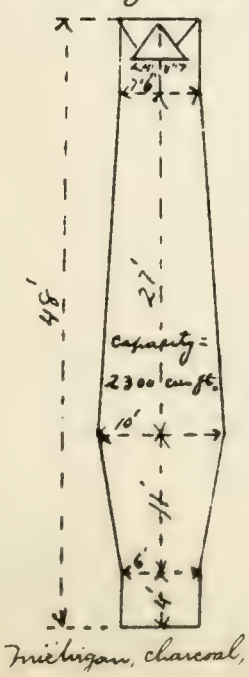


Fig. 65. - This furnace was blown in Mar. 1894; fuel all coke.

Fig. 66. Blown in Apr. 1893. Fuel, all coke. Av. yield (most of the product was Bessemer iron - a little foundry.) was 236 tons per day; 2396 lbs. coke per 2240 lbs. pig. Best day's yield = 275 tons = fuel = 2195 lbs per 2240 lbs. pig.

Fig. 67. Fuel all coke.

Fig. 68. Fuel all coke. Yield = 315 tons per day.

Fig. 69. Lines of Everett Furnace, Everett, Pa., Sept. '94. Fuel, all coke. Yield about 150 tons per day; makes fine grade of foundry iron.

Fig. 69. A. Lines of charcoal furnace in Michigan; yield about 75 tons per day.

For information about furnace lines see A. I. M. E., vol. XIX, p. 932 - "The Development of American Blast Furnaces, with special reference to large Yields", by James Bayley; and "The Irregularities of the Blast-Furnace Process, and a Practical way to avoid them," by Edward Wales, Jr., A. I. M. E. vol. XV, p. 419.

Descent of the Charge.

The descent of the charge in a blast furnace is largely governed by the sizes of the bell and the stock line, both as to arrangement of the particles according to their sizes and also as to their rate of descent.

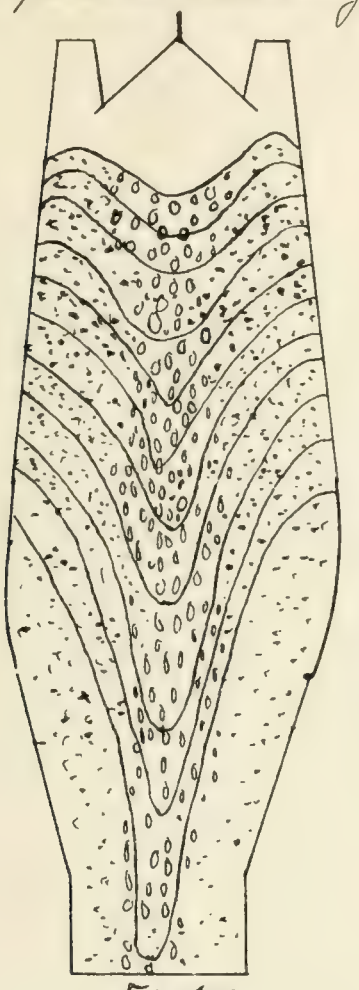


Fig. 70.

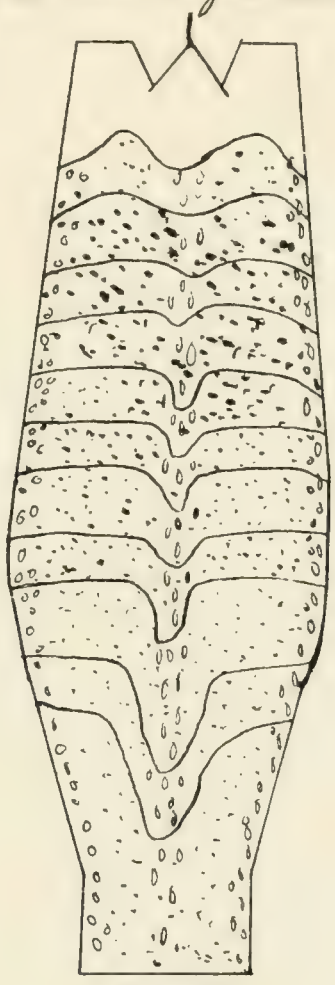


Fig. 71.

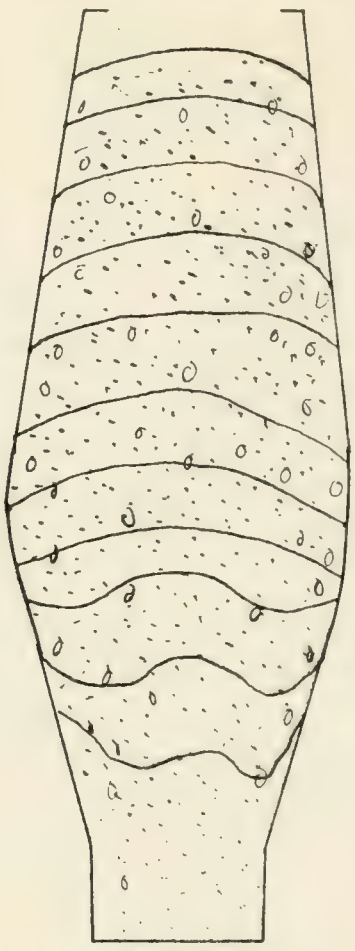


Fig. 72.

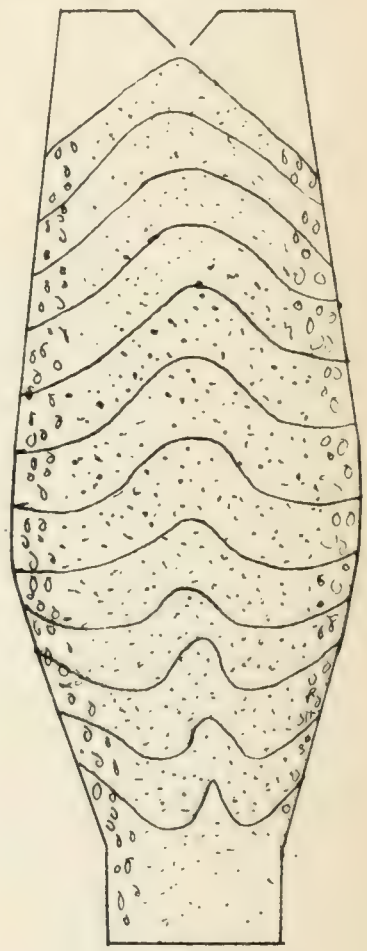


Fig. 73.

Fig. 74

These figures (from A. I. M. E. vol. XVI. p. 149.) were obtained by the use of gravel and sand in a little model furnace, 4ft. high, so constructed that the section showing arrangement of particles could at all times be inspected through a glass plate; the above figures are sketches from the original photographs They show —

1. (fig. 70.) that a large bell rolls the lumps to the centre.
2. (fig. 71.) that a small bell rolls the lumps both to centre and circumference.
3. (fig. 72) that no bell slightly increases lumps towards margin.
4. (fig. 73) that a central feed heaps lumps at margin.
5. that where the fine stuff is at margin (fig. 70) the centre moves down much more rapidly. Where coarse is at margin all moves down with above same velocity. The lines connect particles that have been in the fur-

mace the same length of time. They are isochronous lines.

Fig. 74 shows how a perfectly stationary scaffold can form in this model fed with dry gravel and sand, if only a little obstruction is left for it to rest upon. All the part marked "S" is scaffold. The discharge at the bottom is smaller than that used for the other figures.

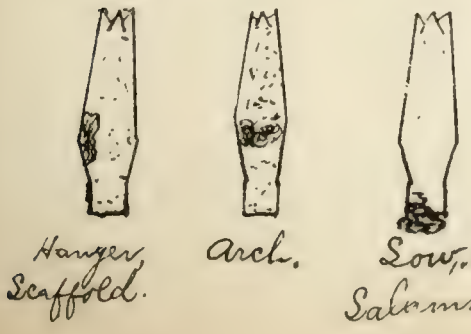
Running Badly.

When a furnace is running badly it is said to be "on a bum". This is generally due to a chill or some irregularity in the working of the furnace. Reduction does not take place where it should and coke is wasted. The chill becomes worse from misappropriated coke; the pig iron goes over from gray (graphitic) to white iron; the slag becomes green and then black and highly charged with iron, and full of shots of cast iron (This mixture of slag and iron is usually called "buckshot"). Wrought iron sometimes reaches the crucible without being carburetted, and builds up, forming so-called salamanders, bears, i.e., large masses of infusible material (wrought iron being infusible, while cast is fusible at the temperature of the crucible.) Sows, also, are of slag, of cast iron (from a chill), and cyanonitride of titanium, from titanic ores.

Causes. Ice, snow, or water on the ores in the stockyard may cause the furnace to chill; faulty mixture of the charge, making it too fusible or infusible may cause a chill; too heavy burden will also cause a chill. The feeders ("top fillers") letting the charge get too low in the furnace, thus giving too high heat in the waste gases, may cause a chill. When cold, dry, N.W. winds (5 grams water per cu. m.) change to warm S.E. winds (17 grms. water per cubic meter) it may cause a chill.

Salamanders may be caused by the bursting of a tuyere, by slow working, the furnace too cold, by titanic ores, by a scaffold, by a chill.

Scaffolds or hangers; these are accretions of solid matter on the walls of the furnace. If the ore is distributed unevenly as to coarse and fine, melting may go too high on one side, and then freeze on and go on accumulating.



Occasionally they arch across, and the material below settles away; a fall, "drop" or "avalanche", then may come, which is very dangerous to the men at the top, and sometimes to the men near the furnace below. An arch is sometimes almost impervious to the blast; this is most difficult to handle; no air, no heat. When the

Running Badly (con.)

arch falls, large quantities of unprepared material come to the tuyeres for melting.

Remedies. When a furnace first begins to "hang" the arch or scaffold may be "dropped" by suddenly slackening the blast. The material that was partly held up by the pressure of the blast will then drop down. If the arch or scaffold can't be removed in this way, the speed of the blowing engine is lessened and the temperature of the blast increased; in this way the furnace gets hotter and the arch is melted away. A more remote remedy is to lighten the burden and change the slag. In a fast-driven furnace a change in the slag will reach the crucible in about 20 hours; in a slow driven furnace it takes about 48 hours for a change to come down, sometimes as long as 150 hours.)

Scaffolds are sometimes removed by "fighting" - or bosh-tuyeres. (See #36, fig. 14, page 15.).

Arches may be removed by explosives. (A.I.M.E. vol. XIII. p. 670.)

Salamanders of slag or of cast-iron may be removed by the petroleum blowpipe (A.I.M.E., vol XV, p. 417) or by explosives (A.I.M.E. vol. X, p. 206).

Wrought-iron and titanic salamanders are removed after the furnace is blown out. They often extend several feet into the foundation and have to be blasted with dynamite, and lifted out by a derrick.

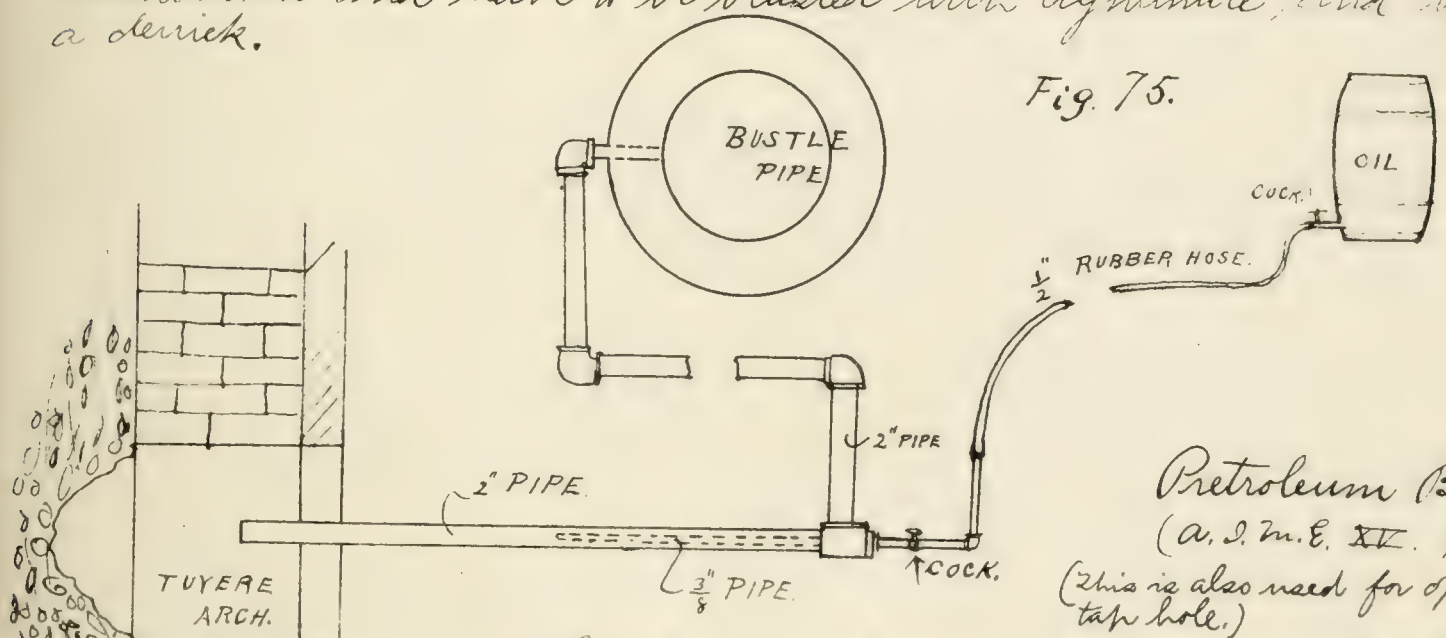


Fig. 75.

Petroleum Blow-pipe.
(A.I.M.E. XV. p. 415.)
(This is also used for opening a chilled tap hole.)

Sometimes a furnace becomes so badly chilled in the hearth that nothing will come out of the tap hole or the cinder-notch and air cannot be blown through the tuyeres. The furnace may be brought back into running order by use of the petroleum blow-pipe (fig. 75). A slight blast is obtained by connecting a pipe to the bustle pipe or to the "cap" of an adjoining tuyere. Coal-oil is fed through the small inner pipe ($\frac{3}{8}$"). The barrel or tank of oil should be high enough to overcome the pressure of the blast. The blow-pipe is applied through a tuyere arch, and the chilled material is melted away until there is an opening through to the cinder notch or another tuyere. The blast may then be put on gently and the cavity enlarged till the blast can penetrate to the loose stock.

6. Pig Iron Classified.

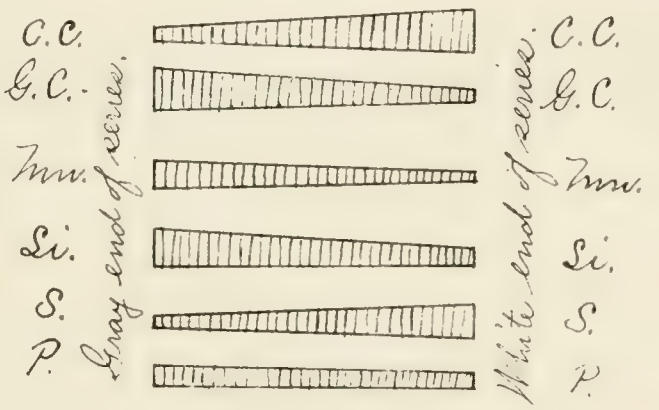
Pig iron may be classified by analysis or by the eye.

Pig iron classified by Analysis. (Ledebur, p. 306. "Eisen und Stahl" - Worlds' Fair Paris, 1878. p. 176)

	C.C.	G.C.	T.C.	Mn.	Si	S.	P.	Cu, Ni	
Terre Noire No. I. -	.94%	- 3.25%	- 4.15%	- 1.25%	- 2.25%	- .02%	- .05	-	Coarse grey foundry
" " " II. -	1.23	- 2.55	- 3.58	- 1.05	- 1.95	- .04	.05		medium foundry
" " " III. -	1.52	- 1.95	- 3.47	- .95	- 1.75	- .06	.05		stands 2 melts
" " " IV. -	2.08	- 1.15	- 3.23	- .65	- 1.55	- .08	.04		fine grey foundry
" " " V. -	2.17	- .85	- 3.02	- .58	- 1.45	- .09	.05	0.26	mottled forge. white.

From which we may say that the tendency to become coarse gray is caused by high graphitic carbon, (G.C.) which in its turn is caused by high silicon. While the tendency to become white is due to high combined carbon which is in its turn caused by lack of silicon. Manganese appears to lessen towards white and increase towards gray; sulphur to increase towards white and lessen towards gray; but these last two are not essential to the conditions of gray and white, the former are.

Graphically.



The vertical width represent relative quantities roughly.

J. M. Hartmann, in Journ. Franklin Institute, CXXXIV, p. 132, gives the following table of typical analyses of the various grades of pig iron

		Iron.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
No.	1.	92.37%	3.52%	0.13%	2.44%	1.25%	0.02%	0.28%
"	2.	92.31	2.99	0.37	2.52	1.08	0.02	0.72
"	3.	94.66	2.50	1.52	0.72	0.26	trace	0.84
"	4.	94.48	2.02	1.98	0.56	0.19	0.08	0.67
		94.08	2.02	1.43	0.92	0.04	0.04	0.02
"	5.	94.68	---	3.83	0.41	0.04	0.02	0.98

"The characteristics and fractures of these grades are:-

"No. 1. Grey. A large dark open grain iron, softest of all the numbers and used exclusively in the foundry. Tensile strength and elastic limit low. Fracture, rough. Turns soft and tough.

No. 2. A mixed large and small dark grain, harder than No. 1 iron, and used exclusively in the foundry. Tensile strength and elastic limit higher than No. 1. Fracture less rough than No. 1. Turns harder, less tough and more brittle than No. 1.

No. 3. Grey. Small grey close grain. harder than No. 2 iron, used either in the rolling mill or in the foundry. Tensile strength and elastic limit higher than No. 2. Turns harder, less tough and more brittle than No. 2.

No. 4. White background, dotted closely with small black spots of graphitic carbon, little or no grain. Used exclusively in the rolling-mill. Tensile strength and elastic limit lower than No. 3. Turns with difficulty, less tough and more brittle than No. 3.

No. 5. White. Smooth white fracture, no grain, used exclusively in the rolling-mill. Tensile strength and elastic limit much lower than No. 4. Too hard to turn, and more brittle than No. 4.

Iron is classified by the eye according to its grain and color. The different districts vary greatly in the exact designations given. I give two instances of local classification:-

New Jersey Anthracite Furnace.

No. 1 X Foundry. coarse grey.
" 1 Foundry. finer "
" 2 X Used for stove castings, mixed with little silver grey, main yield of furnace.
" 2 Foundry.
Gray forge used for American sheet iron.
Mottled.
White.
Silver grey - high Si, used to improve lower grades for foundry.

Michigan Charcoal Furnace.

No. 1. Coarse, grey, soft. } Regular foundry pig.
" 2. a little finer; in centre little fine spot $\frac{1}{2}$" diam }
" 3. " " " " " " " " $\frac{1}{2}$" " - regular car-wheel pig.
" 4. Grey, ranging to white on top and bottom } for special chill castings.
" $4\frac{1}{2}$. " " " " " (more white than No. 4
" 5. Mottled centre. white top and bottom }
" 6. Almost clear white — for casting Lake Superior stamp shoes with a deep chill.

The following special grades are all used in either Bessemer or open-hearth work. (except the ferro silicon.)

Bessemer pig is grey pig with right Si and low S & P.

Spiegel is white with right Mn and low S and P.
(white mirror-like plates.)

Ferromanganese " " " " " " " "
(granular.)

Ferrosilicon " " " Si " " " " "
(very high silicon.) (used in foundry work.)

Classification

Old { Graphitic C.
Combined "

New { 1 Graphite
2 Temper C.
3 Cement C.
4 Hardening C.

1. Graphite, not attacked by acids, hard to burn.

2. Temper C., similar to 1 but found in black spots during prolonged heating of white pig iron. Not yet separated from 1 quantitatively.

3. Cement C. - Fe_3C. Carbon held in soln by Fe. Decomposed by hot acid. Forms in a slowly cooling highly carburetted iron, at a temp. of 660 to 778°C. Increased by slow cooling, diminished by quick cooling.

4. Hardening C. - All the C. in melted iron is supposed to be hardening C. Decomposed by H_2SO_3 + HCl at ordinary temperatures. With HNO_3 at ordinary temp. it remains behind as a black residue, which on heating dissolves and on boiling escapes as a gas.

Jour. Iron + Steel Inst. No 11 - '93 p 61.
Howe's Steel, p. 10.

Pig Iron Classified. (con.)

p. 2

analyses of different sorts of Iron.

		C.C.	G.C.	T.C.	Mn.	Si	S.	P.	Cu Ni Co.	Durre vol. II. p. 295.
Creusot	No. I.	—	—	3.45%	.544%	2.75%	.074%	.772	—	Foundry, coarse grey.
"	" II.	—	—	3.21	.565	2.54	.073	.634	—	finer.
"	" III.	—	—	3.19	.588	2.40	.082	.710	—	fine grey?
"	" IV.	—	—	2.95	.540	2.10	.096	.615	—	mottled.
"	" V.	—	—	2.99	.388	1.81	.120	.680	—	white.

Charcoal Pig. Ledebur p. 302.

Mariazell -	Steiermark.	.11%	3.07%	3.78%	2.52%	1.35%	.05%	.03%	.11%	Grey foundry.
Ilsenburg.		.41	2.78	3.19	.41	2.20	.07	.51	.05	" "

Bessemer Pig.

English	—	—	3.57%	.04%	2.26%	.107%	.073%	—	Ledebur, p. 915.
German.	—	—	3.46	2.99	1.93	—	—		" "
Swedish.	—	—	4.49	.832	1.08	.02	.017	—	"
Bethlehem, Pa.	—	—	3.50	—	2.00	.13	.06	—	Summer School Notes.
Steelton.	—	—	—	—	2.30	.10	.07	—	" " "
Chicago.	—	—	—	—	0.70	—	—	—	a friend.

Basic Bessemer Pig.

Hoerde - Thomas Process	—	3.12%	.41%	.56%	.11%	1.398%	.04% .07		Ledebur.
Ruhrort. "	"	—	3.21	1.03	1.22	.08	2.183	.02 .08	"

Spiegeleisen.

Krupps Works.	—	5.30%	11.30%	Tr.	Tr.	.01%	.16%	Ledebur p. 315.
Reschitza	—	5.39	7.05	.52	.002	.21	.07	" " "

Ferromanganese.

								Fe.	
Hoerde.	—	—	5.31%	55.06%	2.52%	Tr.	.38%	.17%	35.58	Ledebur 317.
Reschitza.	—	—	6.21	69.64	.28	Tr.	.06	.14	23.46	" "
Phoenix.	—	—	6.94	76.95	.02	—	.24	.37	15.44	" "

Silico-Ferromanganese.

Terre Noire	—	—	2.65%	20.50%	10.20%	—	.18%	—	66.75%	" "

7. Properties of Pig Iron.
(See Foundry.)

8. Uses of Pig Iron.

Pig iron may be used in many ways:-

1. Directly without change in Foundry work.

Uses of Pig Iron (con.)

2. By refining – removal of Si and P – followed by dry puddling – removal of C.
3. By wet puddling – removal of Si, P, and C. These yield soft wrought iron for the blacksmith and the roof and bridge builder.
4. By acid Bessemer – removal of Si, Mn, and C. – for rails, and structural mild steels
5. By basic Bessemer – removal of Si, Mn, C, and P. for rails and structural mild steels.
6. By Krupp Washing – Open hearth, or Open hearth alone. followed by Siemens-Martin for mild structural steels, and agricultural tools, car springs, etc.
7. By charcoal hearths including Walloon – for wrought iron – then cementation furnaces for cement or shear steel; and crucible for cast steel for the best tools.
8. Lancashire for nails, wire,

Literature of the Blast Furnace.

most of these books were consulted in the preparation of these notes. The more important ones are marked *.

* Bell, Sir I. Lowthian, — * "Chemical Phenomena of Iron Smelting." London, 1872.
* "Principles of the Manufacture of Iron and Steel." London, 1884.

* Beckert, Th., — "Leitfaden zur Eisenhüttenkunde." Berlin, 1885.

* Dürre, Dr. Ernst F., — * "Die Anlage und der Betrieb der Eisenhütten." Leipzig. 1884. 4 parts. 1st., materials; 2d. Smelting; 3d. Foundry work. 4th. Wrought iron and Steel; 1st. supplement, 1892, "Die neueren Coke-Öfen."

* Gruner, M. L., — * "Studies of Blast Furnace Phenomena," translated by L. D. B. Gordon. Phila. 1874.

* Ledebur, A., — "Handbuch der Eisenhüttenkunde." Leipzig 1884, (edition from which references in these notes were taken; a 2d. edition is just published, 1894)

Lesley J. P., — (Sec. Amer. Iron Assoc.), "The Iron manufacturers' Guide to Furnaces, etc. of U.S." New York, 1859. (has list of all furnaces in U.S. up to 1859 – short descriptions.)

Overman, Frederick, — "The Manufacture of Iron", Phila. 1850. Has drawings of early furnaces.

Percy, Dr. John, — "Metallurgy: Iron and Steel". London, 1864.

Roberts - Austen, W.C., — "An Introduction to the Study of Metallurgy". London, 1894. (chapter on chemistry & bl. furn.)

*Swank, James, — "History of the manufacture of Iron in all Ages". Phila. 1892 (2d. & enlarged edition)

Voesmaer, A., — "The Mechanical and Other Properties of Iron and Steel in Connection with their Chemical Composition." London & New York, 1891.

*Wedding, Dr. Hermann, — "Grundriss der Eisenhütten - kunde." Berlin, 1890.

*"Handbuch der Eisenhuttenkunde", 2d. Edition 1893 & following. (see Percy; this work is an enlarged and revised edition of Dr. Percy's standard book.)

*Wright, Carroll D., — "Sixth Annual Report of the Commissioner of Labor, 1890 — cost of Production: Iron, Steel, Coal, etc." Washington, 1891. (comprehensive book on costs of making iron and steel.)

Periodicals devoted wholly or partly to Iron and Steel.

(In preparing these notes most of the following periodicals were reviewed, especially for the years 1880 - 1894. The initials used in the references in the text are here given after each title.)

"American Institute of Mining Engineers", - Transactions of the, (A. I. M. E.). Annually, New York.

"Bulletin of the American Iron and Steel Association, The", - (B. a. I. S. A.) Weekly, Phila.

"Engineering and Mining Journal, The", (E. & M. J.) Weekly, New York.

"Iron". (Iron.) Weekly, London.

"Iron Age, The," (I. A.) Weekly, New York.

"Jern - Kontorets Annaler". Annually, Stockholm.

"Journal of Franklin Institute". (J. F. I.) Phila.

"Journal of Iron and Steel Institute, The". (J. I. & S. I.) annually, London.

"Journal of the U. S. Association of Charcoal Iron Workers" — "a bi - monthly Publication devoted to Iron metallurgy." (J. C. I. W.) Phila.

"Stahl und Eisen". (St. & E.) Bi - weekly - Düsseldorf - Germany.

Cost of Production of One Ton of Pig Iron (2240 lbs.),
showing kind of pig, and elements of cost.

[d] Establishment number	Locality	Description.	Tons of pig per day.	Height of furnace.	Materials. Ore.	Limestone.	Coke.	Coal.	Total.	Labor	Officials & clerks.	Supplies & repairs.	Taxes.	Total of all cost.
[d] 2.	Northern Dist. U.S.	Hot blast charcoal.	73.	36 Feet.	$4.007	$.173	-----	$9.043 [c.]	$13.223	$1.994	$.261	$.480	$.044	$15.202
8.	Southern " "	" " "	41.	55.	1.981	.235	-----	5.541 [c.]	7.757	1.461	.528	.498	.035	10.279
6.	Northern " "	Cold " "	10.	36.	8.538	.330	-----	11.589 [c.]	20.457	2.982	.880	.920	.060	25.249
20.	" " "	Bessemer	120.	70.	9.009	.491	1.750	[e.] 1.725	12.975	1.250	.091	.500	.028	14.844
21.	" " "	"	236.	75.	10.337	.430	1.891	-----	12.658	1.155	.151	.513	.041	14.518
35.	Continent of Europe.	"	117.	66.	8.756	.265	3.207	-----	12.228	.912	.015	[l.] .279	(l.)	[m.] 13.434
39.	Great Britain.	"	87.	75.	6.387	.264	2.555	.030	9.236	.710	.054	.212	.032	10.244
42.	Northern Dist. U.S.	Foundry #1.	81.	70.	3.680	.517	4.997	[e.] 1.529	10.723	1.983	.238	.624	.023	13.591
113.	Continent of Europe.	" "	(a.)	(a.)	[g.] 3.630	.184	2.971	-----	6.785	[h.] .470	(i.)	[i.] .481	(j.)	[k.] 7.736
55	Northern Dist. U.S.	Gray forge.	123.	70.	[g.] 7.229	.676	2.702	-----	10.607	1.452	.149	.587	.041	12.836
60.	Continent of Europe	" "	93.	(a.)	[k.] 0.837 3.305	.067	4.079	.045	8.333	.425	.066	.227	.022	9.073
74.	Northern Dist. U.S.	Run of furnace.	89.	56.	7.435	.652	2.167	[e.] 2.748	13.002	1.290	.470	.623	.067	15.452
107.	Southern " "	" " "	100.	75.	4.151	.493	4.931	-----	9.575	1.370	.103	.986	.037	12.071

a = not reported.
b. = cost of cinder, scrap, etc.
c = charcoal.
d = numbers used by Wright in his book.
e = anthracite coal.
f = cost of scrap & cinder combined with cost [of ore.
g. = furnace labor proper only.
h. = cost of ordinary labor, officials & clerks combined [with supplies,
i = not reported.
j = not including taxes.
k = taxes & insurance combined with supplies.
l. = including insurance.

The above table is taken from tables in the "Sixth Annual Report of the Commissioner of Labor: cost of Production of Iron, Steel, etc"., by C.D. Wright, 1891. It treats of the costs of production in great detail (iron, steel, coal, coke), and also the costs of livings for the men engaged in these industries.

Foundry.

For a full treatise on this subject, see "Handbuch der Eisen- und Stahlgiesserei", by A. Ledebur, Weimar. 1892.

Castings may require iron to be soft, or hard, or to resist chemicals, or to be strong. Various qualities are produced, some by one element, others by another; and it is to point out how one may select a suitable metal to accomplish a given result that these notes are written.

The usual three grades of foundry iron are ———

No. 1 Foundry, high in Silicon, and coarse graphitic carbon.
No. 2 " lower " " " finer " "
No. 3 " lower still " " " finer still " "

The effect of size in a casting is to retard the rate of cooling if large, and accelerate it if small; the quicker a metal chills the finer the graphite will be. For instance, a large cannon cast from No. 3 pig may have graphite as coarse as what we call No. 1; and a toy carriage wheel cast from No. 1 pig may have graphite crystals finer even than No. 3 pig.

Charcoal and Coke Pig Compared.

Charcoal pig has everywhere the highest reputation and commands the best price; the cause is probably freedom from Sulphur (no S in the charcoal), and probably low silicon (acid slags are used), a little manganese (because Mn is found quite commonly in the limonites used). Coke pig will generally contain more sulphur and less manganese; though it need not be so, and much coke iron is now being used to replace the best charcoal iron.

The Effect of Elements in Cast Iron.

The relative proportion of graphite and combined carbon* (see note on page 61) in a casting is the most important question. As the former increases the metal becomes softer and less strong; as the latter increases it becomes stronger and harder until in the extreme, brittleness diminishes the strength.

For shaping with tools, softness is required. For resistance to wear, as in grinding mills, and to tools, as in burglar-proof safes, extreme hardness is required.

We may say then:—

<u>Graphite</u> is a softener of cast iron.

<u>Combined carbon</u> closes the grain and is a hardener of cast iron.

Effect of Elements (con.)

Slow cooling in large thick castings tends to increase precipitation of graphite making very soft castings. Quick cooling against a chill iron surface, and less so in a very small casting, tends to high combined carbon, low graphite, and great hardness.

Silicon precipitates graphite, and hence its proportion is very important as a regulator of graphite.

Aluminum has the same effect as silicon but is more rarely present. It is used only in very small quantities. Removes included gases + oxides

Manganese increases the capacity of iron for holding carbon in combination, but when present in small quantities seems to act as a softener of iron.

Phosphorus in gray castings up to 0.7% does not injure the castings for most purposes; on the contrary a little of it makes the iron flow well and fill the mould easily. In some castings it may be allowed up to 1.5%. It lowers the temperature of fusion. Chilled white iron is made very brittle by phosphorus.

Sulphur effects the strength of iron very little as it is not allowed above 0.2%. It prevents iron flowing freely in the mould, and for fine sharp castings should not be allowed above 0.06%.

Shrinkage.

Shrinkage appears to increase as graphitic carbon decreases. The following table of pig irons is taken from Ledebur's "Eisen- und Stahl-giesserei", p. 44.

Fracture.	Graphite	Combined carbon.	Silicon.	Manganese	Phosphorus	Shrinkage Coefficient
1. Gray, fine grain	2.08%	2.80%	2.29%	0.86%	0.81%	1/105
2. " " "	2.22	2.71	2.24	0.45	0.93	1/98
3. " " "	2.38	2.88	3.21	1.86	0.90	1/95
4. Not given.	2.89	3.43	1.46	0.75	0.93	1/93
5. " "	2.53	3.45	1.63	1.75	0.85	1/89
6. " "	2.82	2.97	4.21	2.25	0.53	1/87
7. " "	2.64.	3.44	1.39	2.20	0.86	1/78
8. " " somewhat white	0.15	2.92	0.67	0.35	0.98	1/71
9. Mottled.	1.97	1.97	9.50	0.62	0.33	1/70
10. White.	0.49	3.14	0.84	0.26	0.73	1/65
11. "	0.00	3.61	0.99	3.23	0.67	1/58

Manganese increases shrinkage, see numbers 6, 7. Silicon increases graphite and hence decreases the shrinkage. Phosphorus decreases shrinkage.

Resistance to Chemicals.

Sedelur gives on page 64 of his "E. & S." the following table. The numbers are the amounts dissolved by dilute sulphuric acid (sp. gr. 1.05) in 65 hours.

Spiegel.	White cast iron.	Coke Iron #1.	Gray charcoal iron.	Steel.	Wrought iron.
14.1%	19.7%	27.6%	37.7%	66.5%	88.6%

Combined carbon, silicon, and manganese increase the resistance to chemical action.

Melting Temperature.

Gray iron melts at 1200° to 1275° C. White iron melts at 1075° to 1100° C.

Occluded Gases.

Occluded gases are, in part at least, due to the wind pressure in the furnace. To avoid blow-holes melt the iron at a high temperature, cool as far as possible before pouring, pour low to avoid foaming, and use a sink-head which chills later than the casting

sp 54

Choice of an Iron for a Casting.

For most purposes is needed an iron which (1.) shows a gray fracture; (2.) forms no finery scum; (3.) is easily worked by chisel and file; (4.) fills the mould even to the thinnest sections; (5.) chills with a smooth surface; (6.) has moderate strength; (7.) is free from blow-holes; (8.) shrinks but little. These conditions are well filled by an iron containing, after melting and casting:— C, 3.5%; Si, 1.5%–2.0%; P, not over 0.7%; Mn, as little as may be; S, a trace. When such a mixture has been obtained variations may be made. For large castings lower the Si; for small castings increase Si. If shrinkage is to be avoided lower the Mn. If much strength is required lower the C, Si, Mn, and avoid P. If resistance to chemical action is required make Mn as high as brittleness will allow.

Open-bright and silver-gray pig irons and ferro-silicon are used to increase the Si. Spiegel, ferromanganese, and pig iron rich in Mn are used to increase the Mn. Scrap, both wrought-iron and steel, is used to dilute carbon, etc.

Malleable Castings.

To make malleable castings, white castings are packed with oxide of iron in a pot. The pot is then placed in a furnace and kept at an orange heat for about a week, and then allowed to cool slowly. By this means the carbon is largely removed from the outer layers of the casting and the surface is easily cut by tools. Malleable castings are used for elbows, tees, unions, etc., which have to be threaded by machinery.

Furnaces.

Casting direct from the blast furnace is rarely done, as the metal is of too uncertain composition. The beginning of a cast may be white low-silicon iron, and the end gray high-silicon iron.

Cupola melting is the usual foundry practice. It is the cheapest and most expeditious method of remelting.

The reverberatory furnace is however better for large castings. It controls the grain of the metal better and causes fewer blow-holes; but the cost of plant and fuel is higher.

* Note (see page 58.)

Sedebur now distinguishes four forms of carbon; - (1.) graphite, a crystalline form; (2.) temper carbon, separates on strongly heating steel and cooling slowly, appears in spots, is amorphous; (3.) carbide-carbon shows when a polished surface is etched with dilute acid, is a compound of iron and carbon; (4.) hardening carbon which occurs uniformly distributed through the mass; all the carbon has this form when the iron is molten. For further particulars see J. I. & S. I., 1893, vol. II, p. 53.

H. M. Howe distinguishes graphite and combined carbon; combined carbon consisting of cement carbon present as a carbide of iron, and hardening carbon uniformly disseminated through the iron.

These distinctions become more important in steel.

"Kish."

"The formation of kish (noticed especially when "hot" iron is tapped from a blast furnace) is due to the fact that the hotter the iron, the more carbon it can contain. Hence, when cooling the excess of carbon must go out of it, and being lighter it comes to the surface of the bath." (Vosmaer, p. 11.)

Direct Processes.

A direct process is one by which wrought iron is made from the ore in one operation. This operation must be carried on at a low heat, to avoid carburization of the iron, and in the presence of a basic ferruginous slag, to hold the phosphorus in solution away from the iron. The loss of the iron is high (more than 20% of the iron in the ore), but any attempt to replace the iron in the slag by lime means a less fusible slag, and hence higher temperature, more fuel, and carburization of the iron. The production is small and heterogeneous.

H. M. Howe in his "Metallurgy of Steel," vol. I, p. 268 gives a very complete table of the "general scheme of the direct processes", including short descriptions of methods, dates of being first described or patented, fuel consumption, loss of iron, etc. He classifies the direct processes "into those in which the heating fuel serves also for deoxidation, and those in which separate fuel is used for deoxidation."

"The former class may be divided into those (A) which use solid and those (B) which use gaseous fuel; the latter into those (C) in which the ore is inclosed in externally heated retorts, those (D) in which it is heated by a current of hot gas passing through it, and those (E) in which it is treated in open reverberatories." (p. 266, ibid.)

Catalan Process.

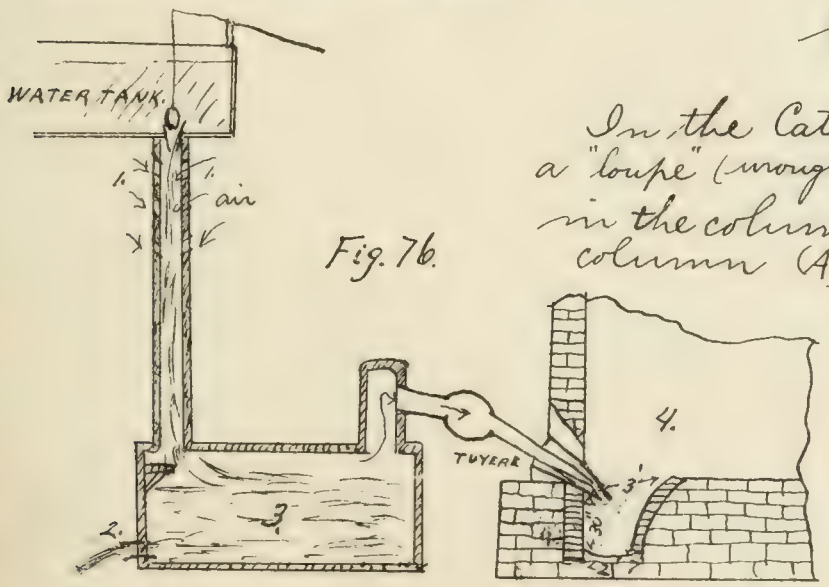
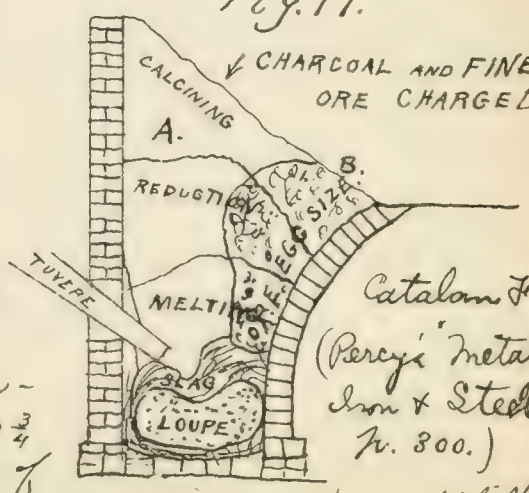


Fig. 76.

CATALAN FORGE AND TROMPE. (VERTICAL SECT.)
("Metallurgy" - Phillips & Bauerman 1887, p. 171)

In the Catalan forge, iron is made from ore into a "loupe" (wrought iron). Ore of egg-size is charged in the column, B., (fig. 77) and charcoal in the column (A.). As the smelting progresses, charcoal and moist fine ore are charged on the charcoal column (A.) as the ore in A. becomes reduced it is worked towards the tuyere. When the ore is all reduced, the loupe is taken out and worked under a hammer to a bloom. The slag is tapped at intervals. One charge of 9½ cwt. of ore (45-48% Fe.) and 10¾ cwt. charcoal, is worked in 6 hours into 3 cwt. of blooms.

Fig. 77.



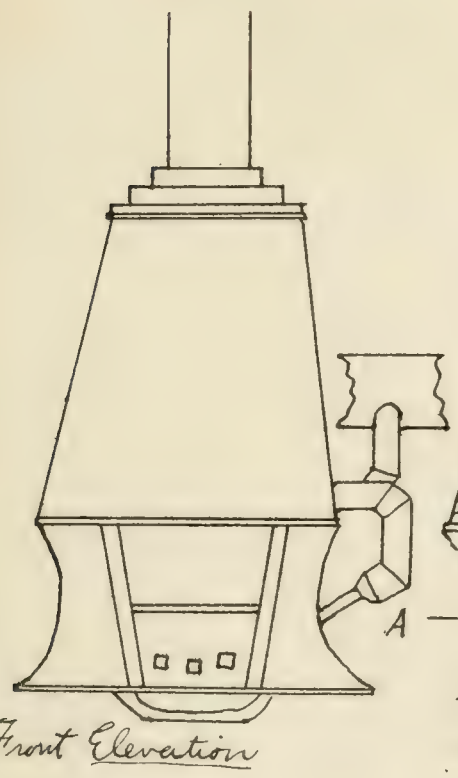
Catalan Forge, (Percy's "Metallurgy Iron & Steel", p. 300.)

Cost per ton of blooms in 1868 was 11£ 8s. (Phillips p. 175.

American Bloomary.
(a low bloomary.)

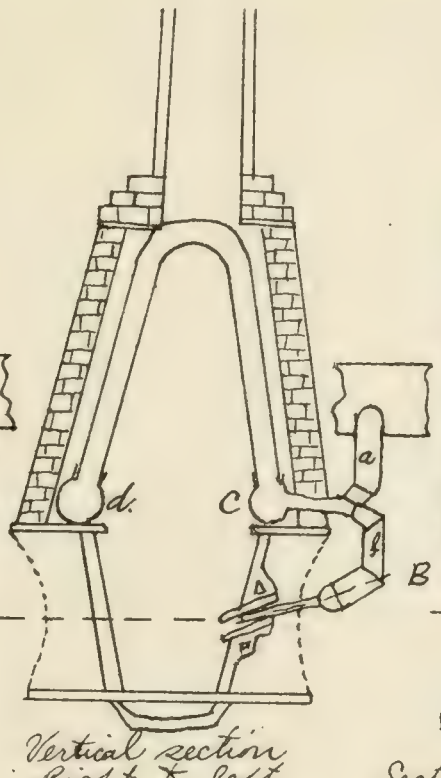
This process is still in use in the Lake Champlain

Fig. 78.



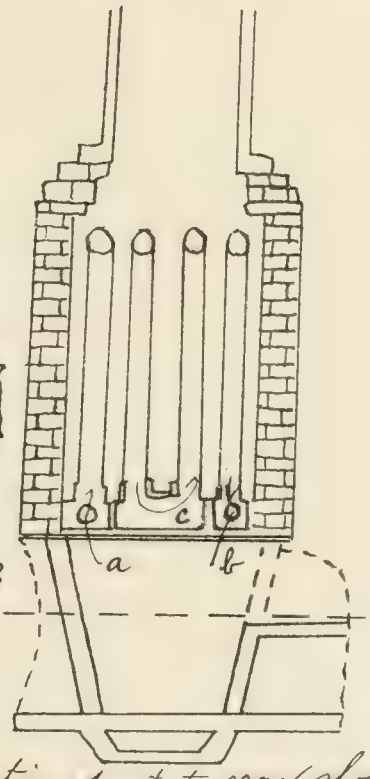
Front Elevation

Fig. 79.



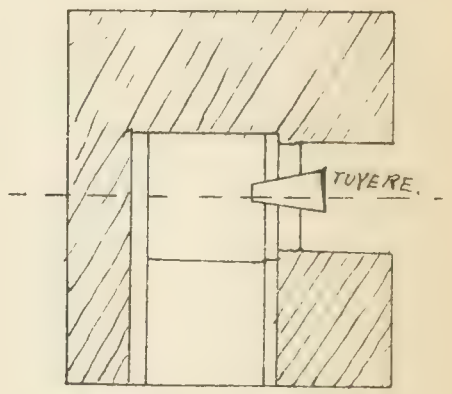
Vertical section
Right to left.

Fig. 80.



Section, front to rear, showing pipes.

Fig. 81.



Section on A–B.
(A. I. M. E. XVI, p. 323.)

(Figs. 78–79–80. from.
(A. I. M. E. VIII, p. 515.)

district. The furnace used is shown in figures 78–81. The hearth is 24–30 inches from front to back, 27–30 inches wide, and 28–36 inches deep. (Howe, "Met. of Steel." p. 270.)

The process consists in reducing rich, calcined ores of pea size, in a charcoal fire with hot blast, to form a bloom. The bloom is reheated and hammered to a billet.

If the ore contains much silica it must first be washed, because, since no flux is used, iron forms the base in the slag and the loss of iron corresponds to the amount of silicon present.

The following analyses of ores and products are taken from an article by Eglekton, A. I. M. E. VIII, p. 515.

	No. 1.	No. 2	No. 3.	No. 4.	No. 5
				Fe_2 = 3.19%	
Fe_2O_3	92.25%	64.55%	92.09%	Fe_2O = 48.57	
$Si O_2$	3.63	30.98	5.95	Fe_2O_3 = 8.06	Si = .095
Mn O.	.02	.14	.12	26.38	Mn = .075
Ca O.	.46	.68	.70	.61	C = .228
Mg O	.56	.58	.36	5.54	P = .015
al_2O_3	.20	1.67	.26	2.29	S = .008
P_2O_5	.076	.13	.16	1.60	Fe = 99.57% (by difference)
S	.235	Trace	Trace	.03	
H_2O	.39	.57	.21	.25	
$Ti O_2$	Trace.			—	
				1.36	

American Bloomary (con.)

No. 1. Saranac ore pure enough for the furnace.
No. 2. Palmer ore, too low grade " " "
No. 3. " " after jigging ready for the furnace.
No. 4. Slag from the forge.
No. 5. Saranac billet.

Egleston also states that one ton of billets is made from 2 tons of dressed ore (65% Fe), and 300 bushels of charcoal in 24 hours.

Cost of apparatus.

Forge —	$600.00
Blower —	3500.00
Wooden hammer	100.00
Iron "	$1200. — $1500.

(a. I. M. E. VIII, p. 549.)

Cost per ton.

	billets	blooms.
Charcoal. 300 bu @ .55 =	$ 16.50	$ 15.13 (275 bu.)
Dressed ore, 2 tons @ 7.00 =	14.00	14.00
Bloomsman.	4.75	3.50
Hammer-man.	2.37	1.87
Stock-man	.60	.60
Other labor	.90	.90
Repairs	2.50	2.50
	$ 41.62	$ 38.50

Osmund Process.

This process is used in Finland for making good iron from high phosphorus ores, hence the large loss of iron (33-50%). The furnace is intermediate between a high and low bloomary, being 8 feet high. (see Howe, "Metallurgy of Steel", vol. I, p. 271.)

Husgafvels Bloomary.
(a high bloomary.)

The furnace used in this process as shown in figures 82-3 is an iron shaft-furnace with a movable hearth. The blast is heated by passing the air spirally around the furnace between the iron casings. (B. B.) The furnace works continuously. Ore and charcoal are charged together at the top. The reduced iron is allowed to collect in the hearth until near the upper tuyere level when the hearth is changed, the charge sticking in place settling but slightly. The slag is tapped at intervals, but enough is always left to cover the reduced iron.

The following analyses and figures taken from Garrison. T. A. I. M. E. XVI. p. 334. and Howe's "Met. of Steel,"

Fig. 82.

Husgafvel's Bloomary (con.)

vol. I. p. 273, show something of what is done by the furnace, and also the heterogeneous character of the blooms.

Ore

Fe_2O_3	=	63.01%
FeO	=	21.06
MnO	=	3.64
MgO	=	3.77
CaO	=	1.58
Al_2O_3	=	3.00
SiO_2	=	4.43
S	=	0.20
P	=	0.12

Slag

contains 7.15% – 40.8% Fe.

Blooms:

(same bloom)	C.	Si	S.	P.
Side –	.07%	.32	.018	—
Centre –	.13	.22	.03	—

(P in some blooms = .04 – .85%)

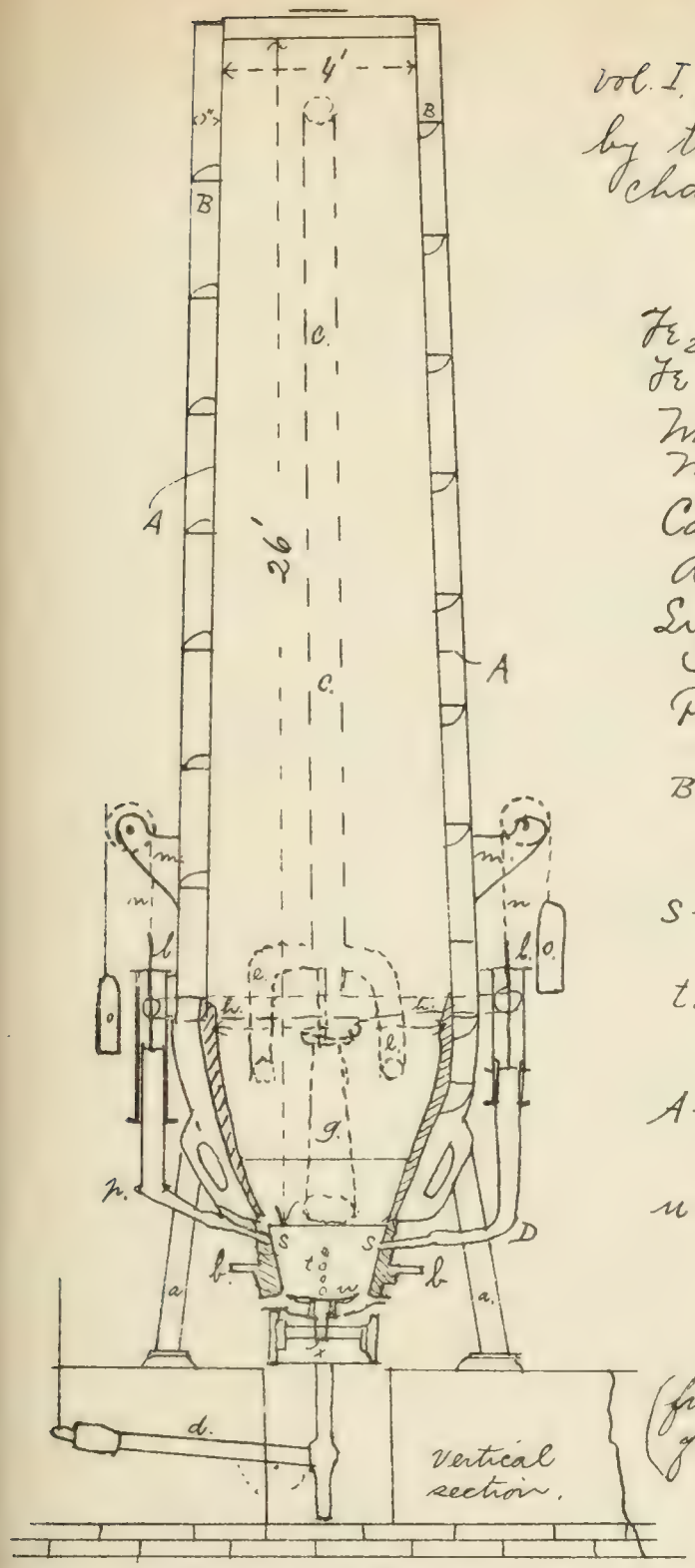
B – spiral partitions – blast heated in in this air-space between the walls.

S – water-cooled tuyere holes.

t. – 4 slag notches at different levels.

A – double, air-cooled, wrought-iron walls.

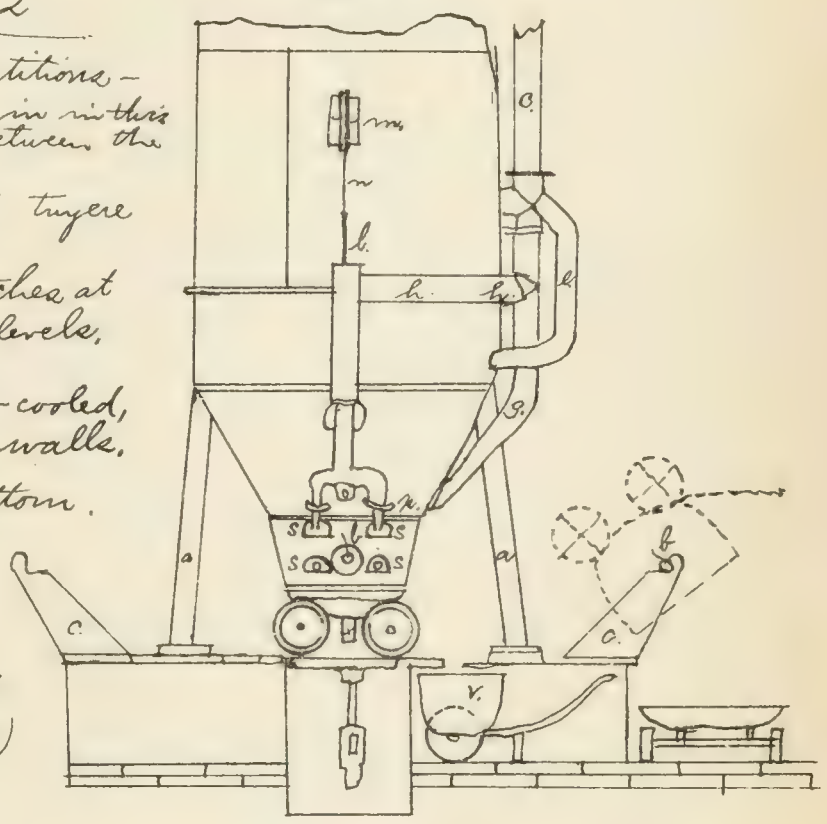
u – false bottom.



(fr. Howe, "Met of Steel, p. 272)

Husgafvel's High Bloomary, at Dobriansky, 1886.

Fig. 83.



Elevation.

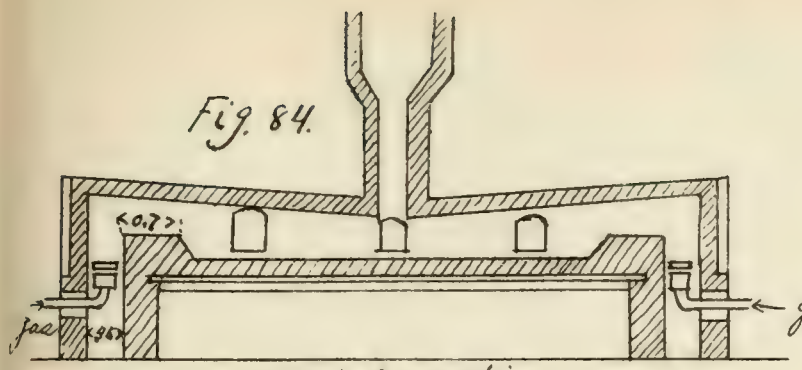
Two tons of ore and 2900 lbs. of charcoal are required to make one ton of blooms. The output is 2.46 tons per day. The cost is about ¼ larger than that of pig-iron.

The Eames Process.

This process is used by the Carbon Iron Company, Pittsburgh, Pa., The furnace is a reverberatory (figs 84. 85) fired at both ends with natural gas. The hearth is made of iron plates covered with about three inches of coke dust.

Eames Process (con.)

Fig. 84.



(from "Oesterreichische Zeit. Berg & Hüttenwesen", 1891, plate XVIII.)

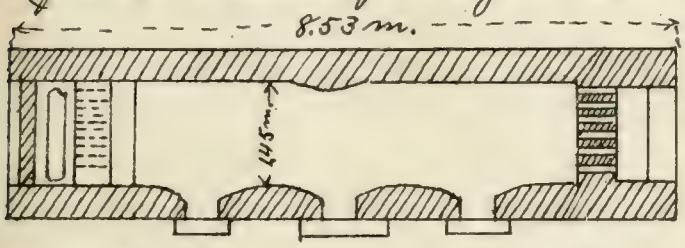


Fig. 85.

Furnace of Carbon Iron Co. Pittsburgh.
(dimensions in metres.)

The reducing agent is "retarded coke" (ground coke or coke dust that has been mixed with "cream of lime" to prevent its rapid combustion.) The charge, which consists of 2240 lbs. of ore and 550 pounds of "retarded coke" well mixed and ground together, requires 3 1/4 hours to be worked in the furnace, and it yields 1550 lbs. of sponge for the open-hearth furnace, or 1160 lbs. of squeezed blooms, or 1000 lbs. of muck-bar (A. I. M. E. XVII, p. 678).

The following analyses were obtained partly at the works and partly from articles by Hunt (A. I. M. E. XVI, XVII.)

	"Section 18" ore.	Minn. Iron Co. ore.	Magnetic concentrates Lake Champlain.	Squeezed Blooms.	Muck-bar.
Fe.	65.00 %	67.00 %	68.00 %	98.47 %	99.02 %
P.	0.011	0.03	0.022	0.02	0.01
S.	0.018	—	0.000	0.021	0.015
SiO_2	—	—	4.00	0.94	0.56
Com. C.	—	—	—	0.150	0.100

The slag contains 25% of Fe.

Some of the iron made by this process is used for high grade crucible steel.

Blair's Process.

Blair's process consisted of reducing ore by charcoal in vertical retorts heated internally by hot carbonic oxide. The process is abandoned. The estimated cost of a ton of sponge was $14.40 (Blair, A. I. M. E., II, p. 195). For illustrations of this furnace see Wedding, "Schmiedbaren Eisens", 1875, p. 556, 557.

Siemen's Direct. Process. (Wedding, "S. E.", p. 269.)

This is another abandoned process. A rotary furnace with regenerative chambers was used for reducing and balling the iron which was then hammered to blooms.

Refining and Puddling.

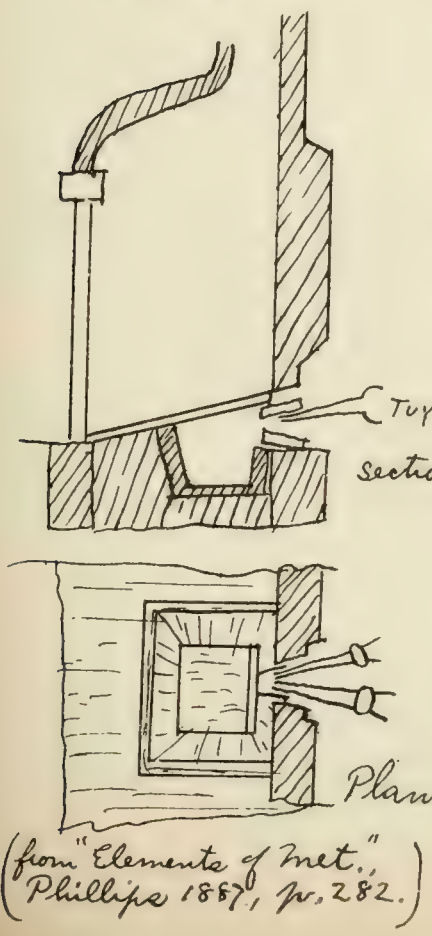
The refining of pig-iron by Charcoal-hearth Refineries or by Puddling converts the cast iron into wrought iron. Refining pig-iron by the Krupp-washing process or by mechanical Puddling prepares material for steel making (Howe, "Met of Steel," p. 289). The more important of these preparatory processes will be treated as follows:-

Swedish Walloon Process, used in Sweden for making blooms for Sheffield steel works.
Lancashire Process, used in Sweden and this Country.
South Wales Process.
Dry Puddling Process, used to make fine wrought iron.
Wet " " " " "
Kruppé- and Bells- Washing-processes for refining-produces a white iron almost free from phosphorus.

The Swedish Walloon Process
(called in Sweden, plain "Walloon".)

This process is used in Sweden solely and exclusively for making bars from Dannemora cast-iron which are to be converted into blister steel. The furnace, or hearth, used is shown in figure 86.

Fig. 86.



(from "Elements of Met.", Phillips 1867, p. 282.)

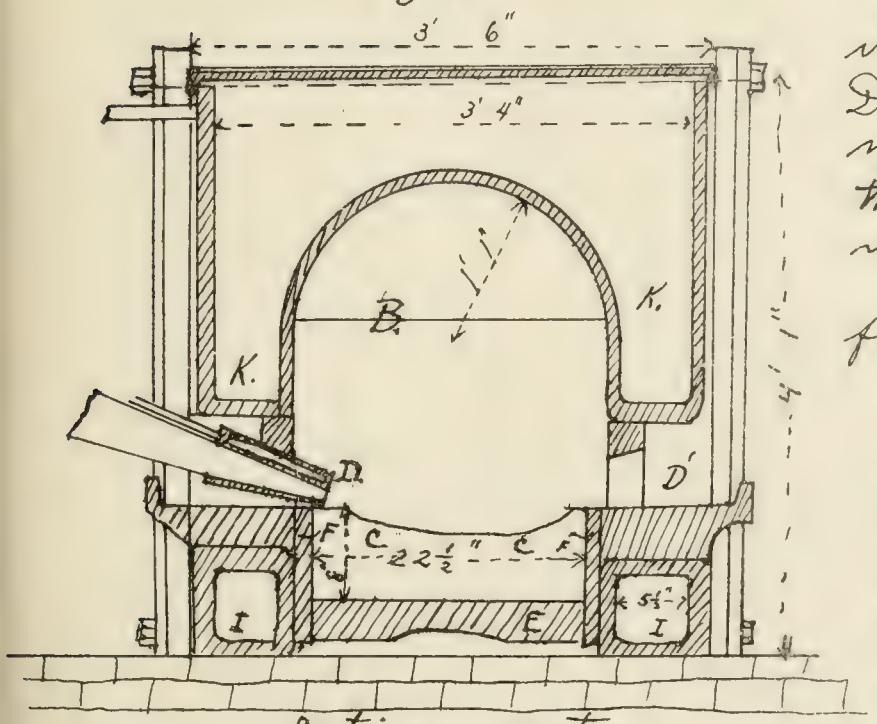
Blast for the charcoal fire is furnished by two tuyeres. A pig of iron 15 to 20 feet long is fed to the forge on rollers till about 100 lbs. is melted off. As the metal melts the drops of iron pass in front of the tuyeres and lose a large proportion of their Mn, Si, P and C. Some of the iron also is burned to oxide. The FeO and SiO_2 combine to form a cinder which is tapped off from time to time. The pasty mass which is partly refined collects in the bottom, and is now rolled up into a lump and raised to the top of the charcoal, and allowed to melt down a second time together with the richer slag and hammer scale. This time the refining should be completed and the metal is ready to be balled up into a bloom and to be sent to the hammer. The hammered bar is shipped to England for steel making (especially to the Sheffield steel works for fine grades of steel.)

Walloon Process (con.)

To produce 2,000 lbs. of blooms, 4250 lbs. of charcoal and 2640 lbs. of pig iron are required. The loss of iron is 24%. The capacity of the furnace (or forge) is 3900 lbs. per 24 hours. The blooms are decidedly heterogeneous because the iron that is first melted is exposed to the blast longer than that melted later. Hence the first-melted part is much further decarburized than the last-melted part and this is not wholly remedied in the remelting. The blooms are probably inferior to those produced by the Lancashire process. (Howe, "Met. of Steel," pp. 292, 295.)

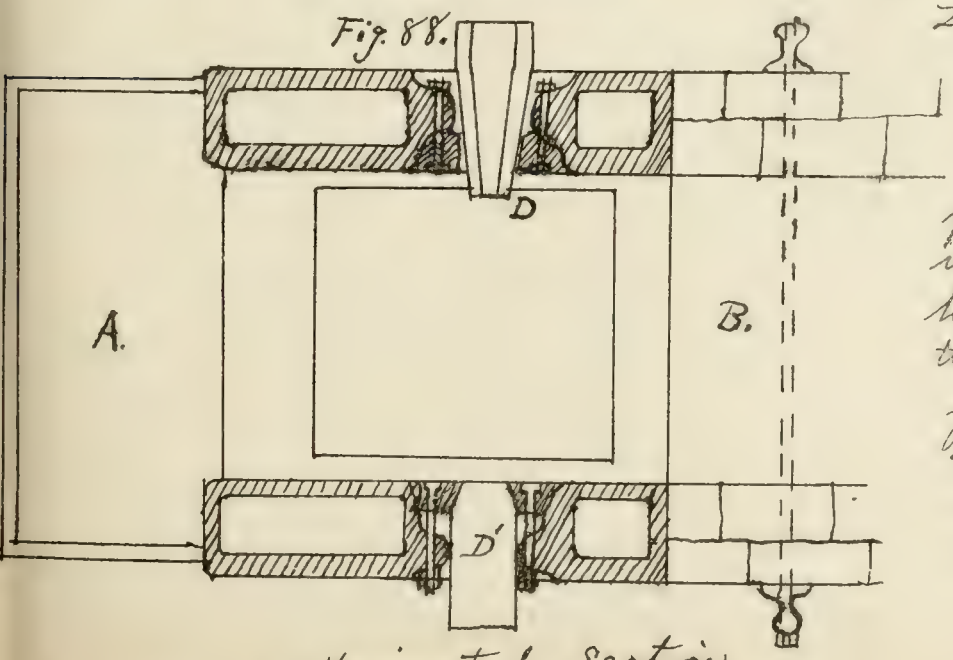
Lancashire Process.

Fig. 87.



Section on centre.

Fig. 88.



Horizontal Section.

(Howe, "Met. of Steel," vol. I, p. 289)

"Nearly all the charcoal-hearth iron made in Sweden, other than Dannemora iron for cementation is made by the Lancashire process; this process is also used extensively in this country." (Howe.)

The hearth used is shown in figs. 87 and 88.

A = Fore- or working-plate.
B = Shelf for preheating the cast-iron.
C = The hearth proper.
D = water cooled tuyere.
E = water cooled, cast iron bottom-plate.
FF = cast iron side plates.
I = " " water cooled boxes.
K = " " " " roof and sides.

There is a tuyere at D' also.
Under A is a tap-hole for slag.

The waste gases heat the pig iron, placed on B, before it is charged. After the hearth has been filled with charcoal, the preheated pigs are brought forward onto the fuel, and melted down. The pasty mass which collects on the bottom is broken up with bars, and mixed with the decarburizing slags. When the mass is nearly decarburized,

Lancashire Process.

it is raised above the tuyere and melted down again, collecting in a ball which is drawn and hammered.

It requires 947 lbs. of charcoal and 2300 lbs. of pig iron to produce 2000 lbs. of blooms. The capacity of a furnace is 5300 lbs. per 24 hours. The loss of iron is 13% (Howe, p. 292.)

South Wales Process.

This process was formerly used extensively in South Wales, especially for making plates for tinning. It has been driven out to a great extent, if not altogether by the Bessemer and open-hearth processes. (Howe, p. 293.)

The pig-iron is first melted in a coke refinery (see Percy, Met. of Iron & Steel, p. 584) where it loses part of its silicon and carbon. It is then tapped into two charcoal-fineries where the iron is worked very much as in the Lancashire process, but when it is decarburized it is removed without the final melt of the Lancashire process. (Howe, 295.)

Puddling.

By Puddling in a reverberatory furnace pig iron is converted into wrought iron. The older and now less common method of Dry Puddling is applicable to the treatment of white or refined metal only. In the dry method the pig-iron is simply brought to a pasty condition in the puddling furnace, and the necessary oxygen for removing the impurities is furnished chiefly by atmospheric air. While in "Wet-Puddling" or "Pig-boiling", the pig-iron is melted during the process, and most of the oxygen for removal of impurities is furnished by the slags and the oxides of iron added.

In Dry Puddling the pig-iron is first refined in a refinery or "running-out fire" (see Greenwood's "Steel and Iron", 1884, pp. 238, 240). The iron is then cast into slabs about 3 inches thick, cooled suddenly by water so as to make it very brittle, and is then broken up, and treated in the puddling furnace. Dry puddling is not used in U.S.

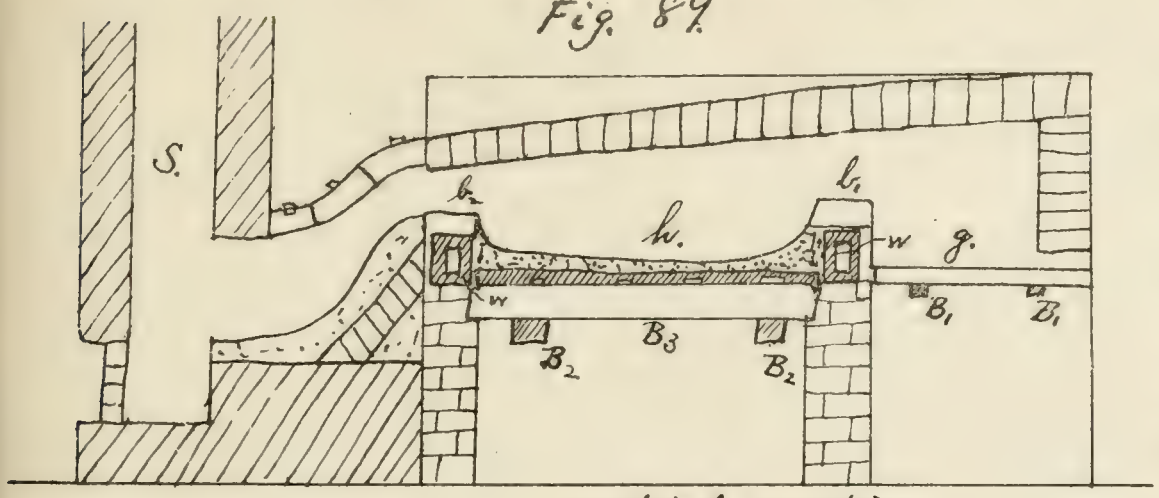
Sometimes the gray iron is run directly from the blast furnace into the refinery.

In amount of production Wet Puddling is much more important, and is the process used in this country.

Wet Puddling.

The puddling furnace (fig. 89.) is a reverberatory with large grate and small hearth for obtaining intense heat. The fuel used is soft coal or natural gas.

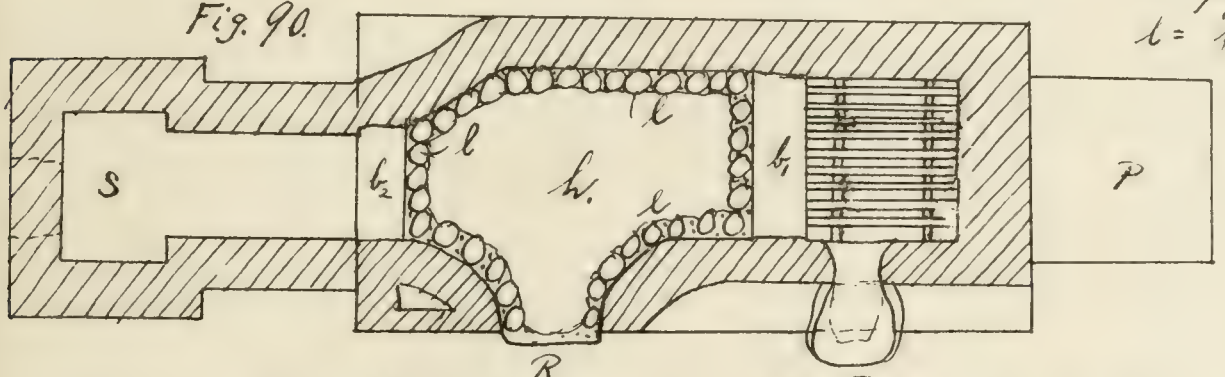
Fig. 89.



vertical section.

F = fire door.
g = grate.
h = hearth.
b_1 = fire bridge.
b_2 = flue bridge.
R = rabbling and working door.
S = stack
B_1 = grate bearers.
B_2 = hearth bearers (across.)
B_3 = " " (lengthwise.)
P = pit for cleaning grate.
l = "fettling" or "fix".

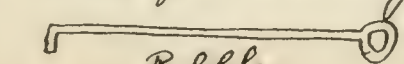
Fig. 90.



Puddling Furnace – horizontal section.
(fr. Percy. "Met. of Iron & Steel", pps. 642, 651, combined.)

The bridges are supplied with water-cooled blocks (W, W) and the hearth is made of iron plates.

In wet puddling a grayer iron (unrefined) which carries more Si than the white iron is used, and it is kept at melting heat during the whole operation. A considerable quantity of high grade hematite or magnetite is used as a reagent for oxidizing the impurities. These materials are called "fettling" or "fix", and a furnace is "fettled" or "fixed" by putting in lumps of iron ore all around the hearth, filling up the spaces between with a paste of ground hematite called "puddlers mine". The fettling has to be repaired after every heat. The hearth has to be repaired with scrap iron after every 12 hour shift.

After charging the furnace, 30 minutes of strong heat are given for melting the pig; then 15 minutes of lower heat for rabbling and incorporating the metal with the detached portions of fix, and mill-scale which is added. Then follows 15 minutes of violent boiling with elimination of CO_2 from the reaction between the carbon of the pig and the oxygen of the ore, moderate heat is used and the "rabbling" is kept up all the time. (The "rabble" is a bent iron tool for stirring or rabbling the iron. It is shaped like this ). The boiling soon

Rabble.

Puddling (con.)

ceases, the cinder lowers, and points of white-hot iron are seen projecting everywhere; the iron has come to nature". The heat is raised somewhat and the iron is balled up, and balls weighing 80 lbs. or so are taken to the squeezers, and then to the rolls and made into "muck bar."

If the pig contains much Si., 4 to 5 heats only are made in 12 hours; 4½ cwt. of pig forms a charge. The loss with high Si pig is 15 to 18% in the cinder. Cinder contains from 8 to 25% SiO_2, and the rest is mainly FeO with a little CaO, Al_2O_3, Fe_2O_3, P_2O_5; it contains 45 to 55% Fe. Puddling removes 80% of the Phosphorus as P_2O_5 in the cinder; but only imperfectly removes Sulphur.

The following analyses taken from Ledebur's "Eisenhütten-kunde", pp. 797 and 800, show what occurs in the puddling furnace.

Analyses of the Iron.

	C.	Si.	Mn.	S.	P.
Pig iron, before melting	2.57%	3.21%	5.14%	0.04%	0.97%
after 43 min., end of melt.	2.80	1.09	2.68	0.016	0.58
" 52 " beginning of boil.	2.89	0.23	2.53	0.013	0.56
" 55 "	2.78	0.21	2.20	0.012	0.30
" 62 " {beginning to come to nature; violent boiling.	2.63	0.22	1.31	0.012	0.25
" 91 "	1.65	0.23	0.65	0.012	0.21
96 96 " Beginning of balling-up.	1.38	0.21	0.32	0.011	0.18
" 109 "	0.86	0.11	0.28	0.010	0.17
The "muck-bar"	0.63	0.09	0.15	0.009	0.12

analyses of the accompanying Slag.

	SiO_2	FeO	Fe_2O_3	MnO	Al_2O_3	CaO	P_2O_5
Slag remaining in hearth.	15.32%	52.18%	22.81%	6.56%	0.33%	0.70%	2.30%
" after 43 min.	20.50	54.61	7.72	12.38	0.41	0.80	4.30
" " 52 "	23.18	52.43	6.94	12.51	0.49	0.83	4.22
" " 55 "	20.37	57.06	9.04	10.10	0.30	0.51	3.49
" " 62 "	19.95	51.68	11.45	11.69	0.27	0.50	4.26
" " 91 "	21.91	46.76	12.36	15.87	0.30	0.43	3.10
" " 96 "	19.45	48.04	13.48	14.40	0.34	0.62	4.17
" adhering to the ball of iron.	16.29	51.62	19.32	8.46	0.38	0.61	3.78

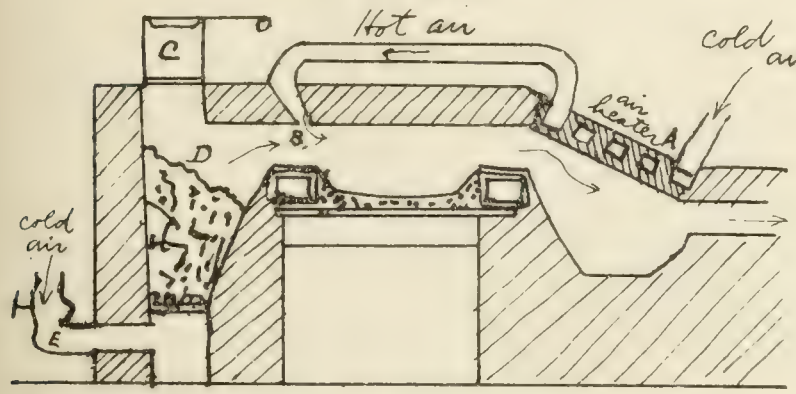
Wet puddling is the universal puddling process in the U.S., but it is gradually giving way to Bessemer and open hearth mild steels. Wrought iron, however, on account of the little slag it contains welds so much easier than mild steel that the blacksmith still wants his wrought iron. "Merchant bar" is "muck bar" that has been cut, piled, reheated, and rolled. Having the centre of the pile made of ordinary scrap iron; in this case, a low grade bar iron is the result. "Norway iron" is the best muck bar that has been cut, piled, heated, and rolled. It contains a little slag among its fibres, this together with its softness

Puddling (con.)

and purity makes it the best metal for the blacksmith.

The puddling process costs high for fuel, 1 ton of coal to a ton of muck bar being a fair average. The work is very severe on the men. On these accounts many efforts have been made to save fuel and reduce labor. For saving fuel Siemens adopted the regenerative principle to a puddling furnace, but this has not found favor.

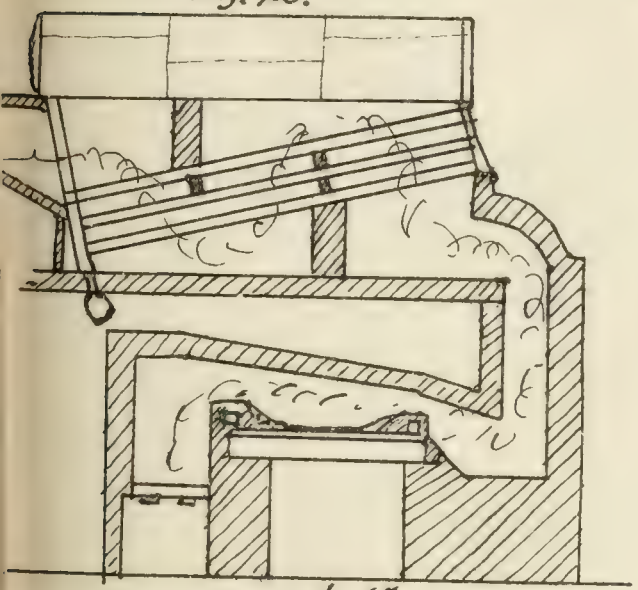
Fig. 91.



Carinthian Gas Furnace for Puddling.

In Carinthia a gas furnace (fig. 91) is used. Air is heated in the cast-iron heater (A) which covers the flue. The heated air passes through a pipe and enters the furnace at B just over the bridge. Turf or air-dried wood is fed in at the hopper C and CO is generated in the gas-generator D. Cold air enters at E. (Phillips's Metallurgy, p. 296.)

Fig. 92.



B. and W. Boiler over Puddling Furnace.

The waste heat of the puddling furnace is often used for heating boilers which are mounted over the furnace as shown in fig. 92. The fluctuating heats of the furnace have a very serious influence on the life of the boilers especially when cylinder or two flue boilers are used. Babcock and Wilcox boilers mounted in this way have given entire satisfaction in many iron plants in this country. ("Iron Age", Apr. 6, '93.) (Fig. 92 shows setting used at Oliver Iron and Steel Co. Pittsburg.)

Danks Puddling Furnace.

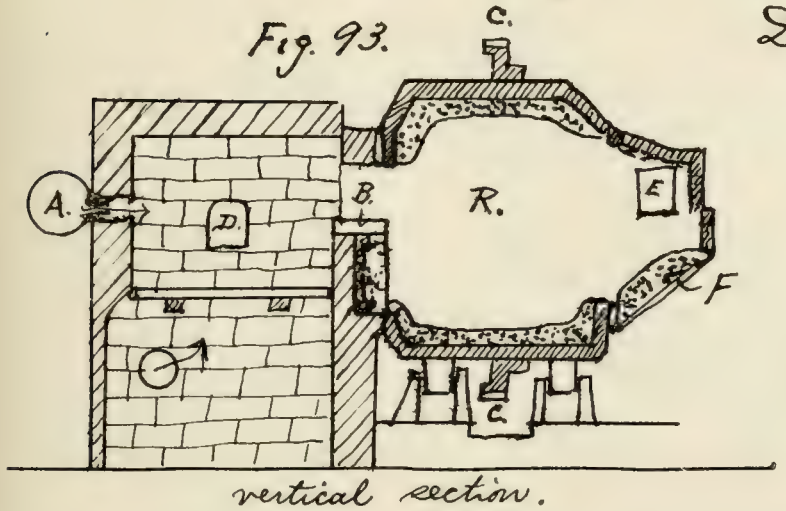
For saving labor in puddling, mechanical furnaces have been used. The most efficient and the one which finds the most favor is Danks Rotating Furnace (figs. 93, 94) It is shaped much like a short very large barrel lying on its side, supported by four friction rollers, two at each end, and driven by a large gear around its middle. The setting is of iron ore worked in in layers at a low heat. It is fed with molten iron from a ladle. At Pittsburgh it is used for ordinary

puddling work. At Cleveland it is used for making wrought iron for the open hearth. There 1½ tons are brought to wrought iron in 15 minutes. The mass is removed by a great spatula suspended from a crane and manipulated by the men; it is carried to a hammer where it is compacted and then cut up into blocks for the Siemens furnace.

Bell, in his "Principles of the Manufacture of Iron and Steel," p. 388, gives the following comparative table:-

	C.	Si	S.	P.
Cleveland pig contains, say -	3.50%	1.75%	0.15%	1.55 %
" " when refined -	2.50	0.091	0.11	0.50 to 0.75
" "refined & dly puddled -	Nil.	0.19	0.01	0.26
" " hand puddled, wet -	Nil.	0.159	0.041	0.324
" " mechanically puddled -	Nil.	0.109	0.032	0.10 to 0.17

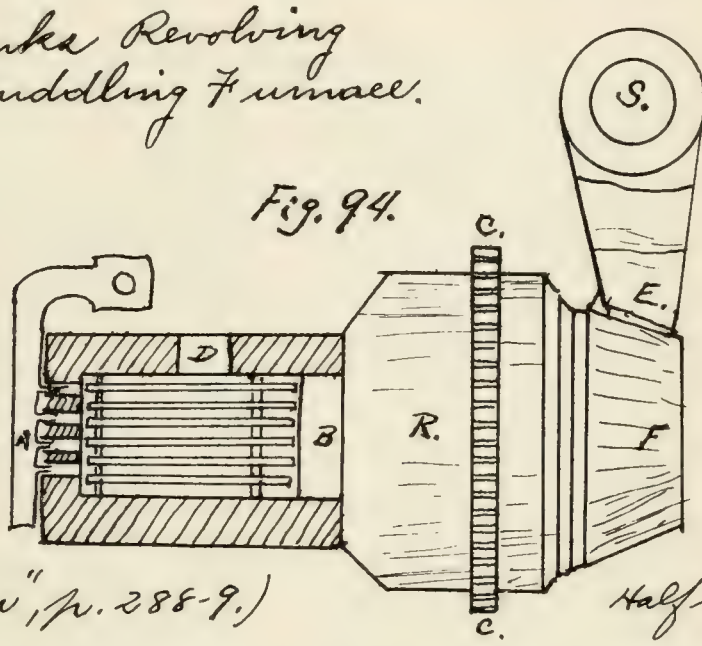
Fig. 93.



vertical section.

Danks Revolving Puddling Furnace.

Fig. 94.



Half in section.

(From Greenwoods' "Steel and Iron", p. 288-9.)

A = blast-pipe. C. = toothed wheel. D = firing door. E = flue to stack. F = movable flue-piece. R = Revolving chamber or hearth. S = stack.

Elements of Cost of One Ton of Puck Bar Iron. (2240 lbs.)

Locality.	No. of Puddling Furnaces.	Materials. Pig Iron.	Scrap.	Ore.	Gross. Total.	Val. of Cinder, Scrap etc.	Net.	Labor.	Officials and Clerks.	Fuel.	Sup-plies & Repairs.	Taxes.	Total.
United States	47.	$10.993	(Reckoned with pig.)	$2.730	$13.723	$0.170	$13.553	$7.746	$0.244	$2.028	$0.313	$0.080	$23.914
" "	33.	16.305	.366	1.426	18.097	0.362	17.735	7.155	.324	.711	.870	.053	26.848
Cont.-Europe.	9.	10.230	—	.206	10.436	—	10.436	2.626	.283	2.113	.903	.108	16.469
Great Britain.	30	8.312	.686	+ .019* .389	9.406	.111	9.295	2.368	.038	1.909	.675	.016	14.301
" "	35	9.357	.071	.781	10.209	.235	9.974	3.463	.068	1.641	.658	.014	15.818

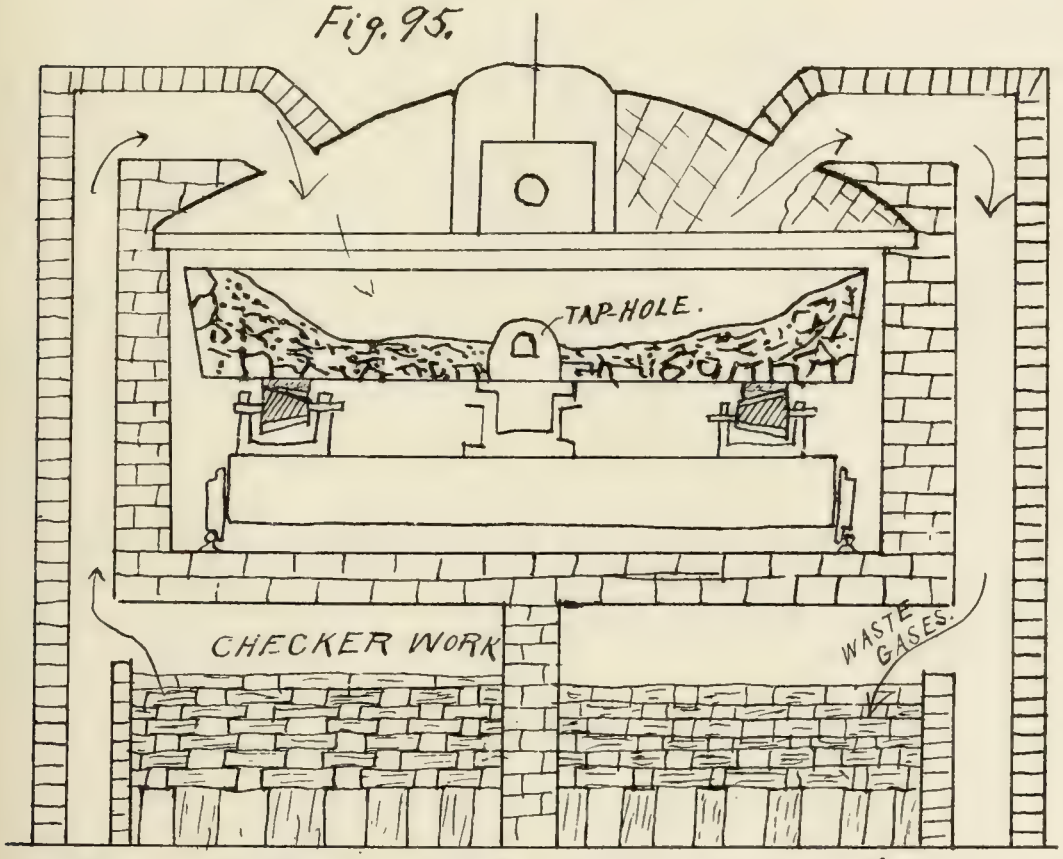
* = cinder

These figures are from "Sixth Annual Rep. Com. Labor", 1890, p. 114.

Krupp Washing Process.

Pig irons which are too high in P. for steel making, can be washed nearly free of it, provided the Si. is not too high. The process consists in agitating molten pig iron in contact with a basic slag rich in FeO, in a furnace lined with iron ore; 85 to 95% of the P. is washed out. Sulphur is also reduced in like proportion. The product, called "washed metal", is used for making steel by the Open Hearth process. The pig iron most suitable should have P. below 0.50%, Si about 0.75%, S = .08%, Mn. as much as 1.50%, and C = 3.50%. High Si. is bad because it wears away the oxide lining of the furnace, increases the loss, and uses up the bases in the slag and so hinders the oxidation of the P. Mn. is advantageous as it protects the C. The washed metal must not have over .04% P, .02% S. It will be free from Si. and Mn., while C will be 2.5 to 3.0%.

Fig. 95.



Pernot Furnace for Krupp Washing.
Cambria Iron Co.

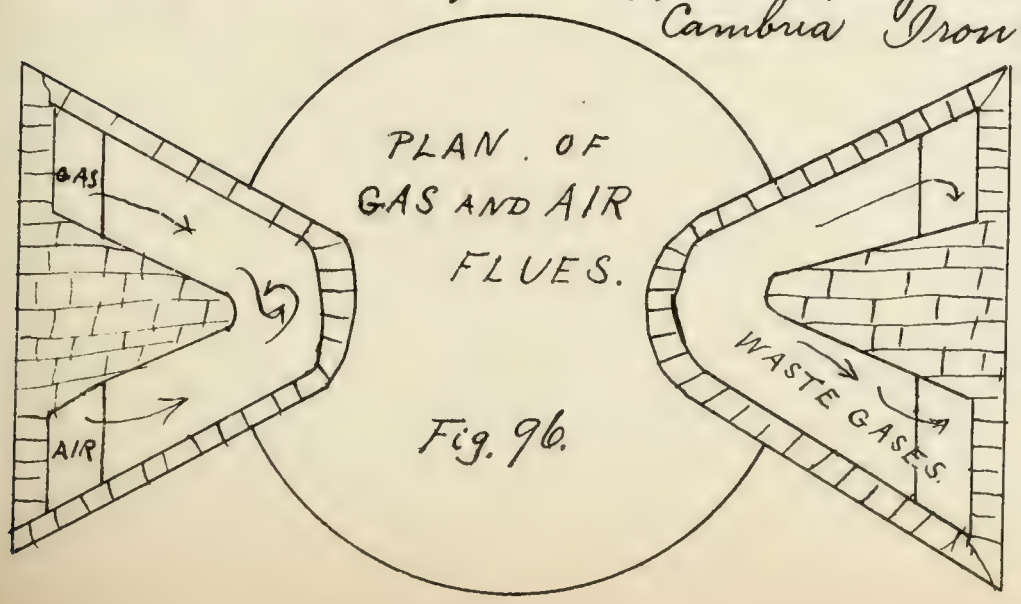


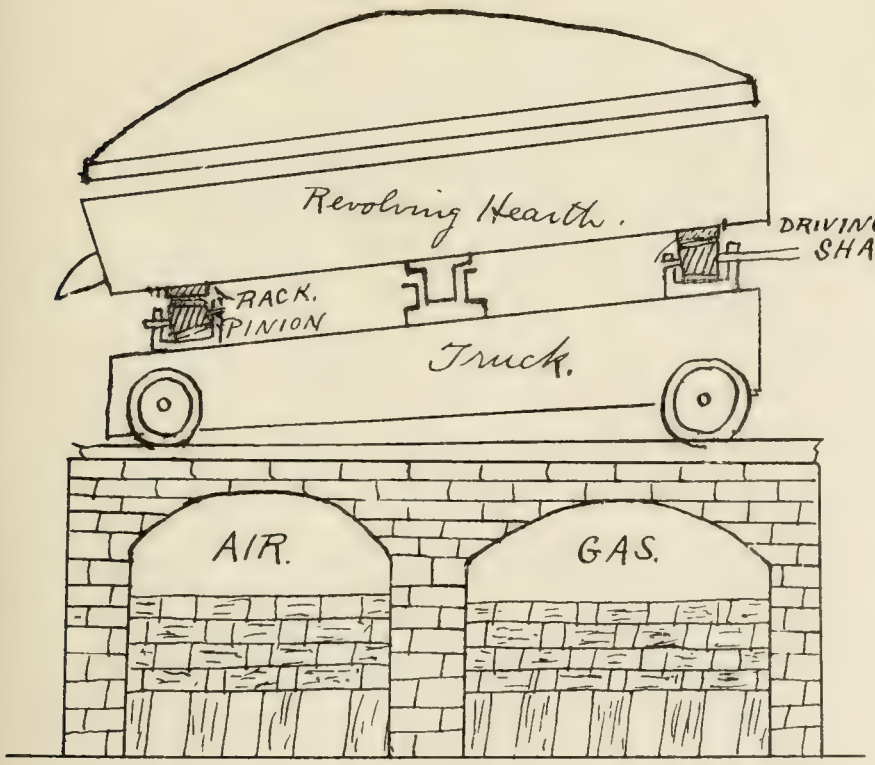
Fig. 96.

The furnace used is the Pernot revolving hearth (fig 95, 96, 97) which has an oblique plane of revolution. The hearth, shaped like a pan sets on a truck, upon which it revolves about a pivot; the truck runs on a track. The hearth can thus be drawn out from under the roof for repairs. The hearth is lined with a thick, sloping wall of blocks of magnetite low in SiO_2, the joints and inside face being filled up with fine ore having 5 to 12% of SiO_2. Too much SiO_2 will make the slag too acid; a little helps the ore to adhere. This lining is softened and sintered together by heating

up the furnace to a red heat. The molten iron may be obtained in either of two ways :—

(1.) From a cupola (remelted pig iron.)
(2.) From a blast furnace (direct iron; see fig. 98.)

Fig. 97.



arrangement of Hearth & Truck.

To prevent the wearing away of the ore lining by the Si. and P. of the charge, additions are charged into the furnace before the operation, of enough bases to satisfy the Si and P.; these consisting of low silica ore, roll scale, and lime; 20% of the weight of the pig is sometimes used.

After 3 to 5 minutes in the furnace during which the hearth is revolved 11 times per minute, the iron ore begins to react with the Si and P., and in 5 minutes more the carbon begins to burn and the charge boils violently. The object now is to hold back the oxidation of C. in order to give the P. time to be brought in contact with the O, and also to retain most of the C. so as to keep the bath liquid enough to flow out of the tap hole at the end of the operation, by the use of a low heat. If it were continued until the C. was too much reduced the bath would become thick as in puddling.

The conditions governing the process are ——— (1.) Basicity of slag; (2.) Time; (3.) Temperature.

If slag is not basic enough P. is not all washed out. SiO_2 in slag must be below 20%; if up to 30% no P. will go out. (Bell, "Principles of Mnfg. I. & S. p. 400). A Cambria Iron Co. slag in which there was 23% of SiO_2, the amount of P. eliminated was 70%. Another slag having 18.5% Si the % of P. washed out was 85%.

The longer the metal is kept in agitation with the slag the more completely is P. eliminated; 30 minutes will usually remove all but traces.

A low temperature in the furnace favors the union of P. with the oxides. (Bell, "Prin. of Manf. I. & S.," p. 397). It also retards the union of C. and O. But

high temperature increases the liquidity of metal and slag and so helps them to mix. The proper temperature must be between these extremes.

Analyses. (from a. I. M. E. vol. VIII, p. 158.)

	C.	Si.	P.	S.	Mn.
Raw Pig ------	3.30%	0.39%	0.74%	0.09%	2.32%
after 7 minutes ---	3.32	0.023	0.106	0.029	0.058
{Finished metal after 30 minutes} ---	2.50	Trace.	0.01	0.02	Trace.

	$Li O_2$	FeO.	MnO.	Al_2O_3	CaO.	P_2O_5	SO_3
Slag ----	13.0%	51.0%	16.6%	11.6%	0.7%	6.0%	0.2%

Costs of Krupp Washing Process —
Pig Iron per ton = $10.00; Fuel = $.70; ore, etc = $.75
labor = $1.25 total, per ton washed metal = $12.70

The process is worked most successfully in connection with a blast furnace, where the iron can be taken direct from the blast furnace into the washing furnace (fig. 98.) Between the blast furnace and the washer is placed a storage reservoir, consisting of a pear shaped vessel lined with fire brick and mounted on a hydraulic ram. This is filled from the blast furnace; and as it is wanted in the washer, is poured from the reservoir, or "mixer", by raising it by the ram.

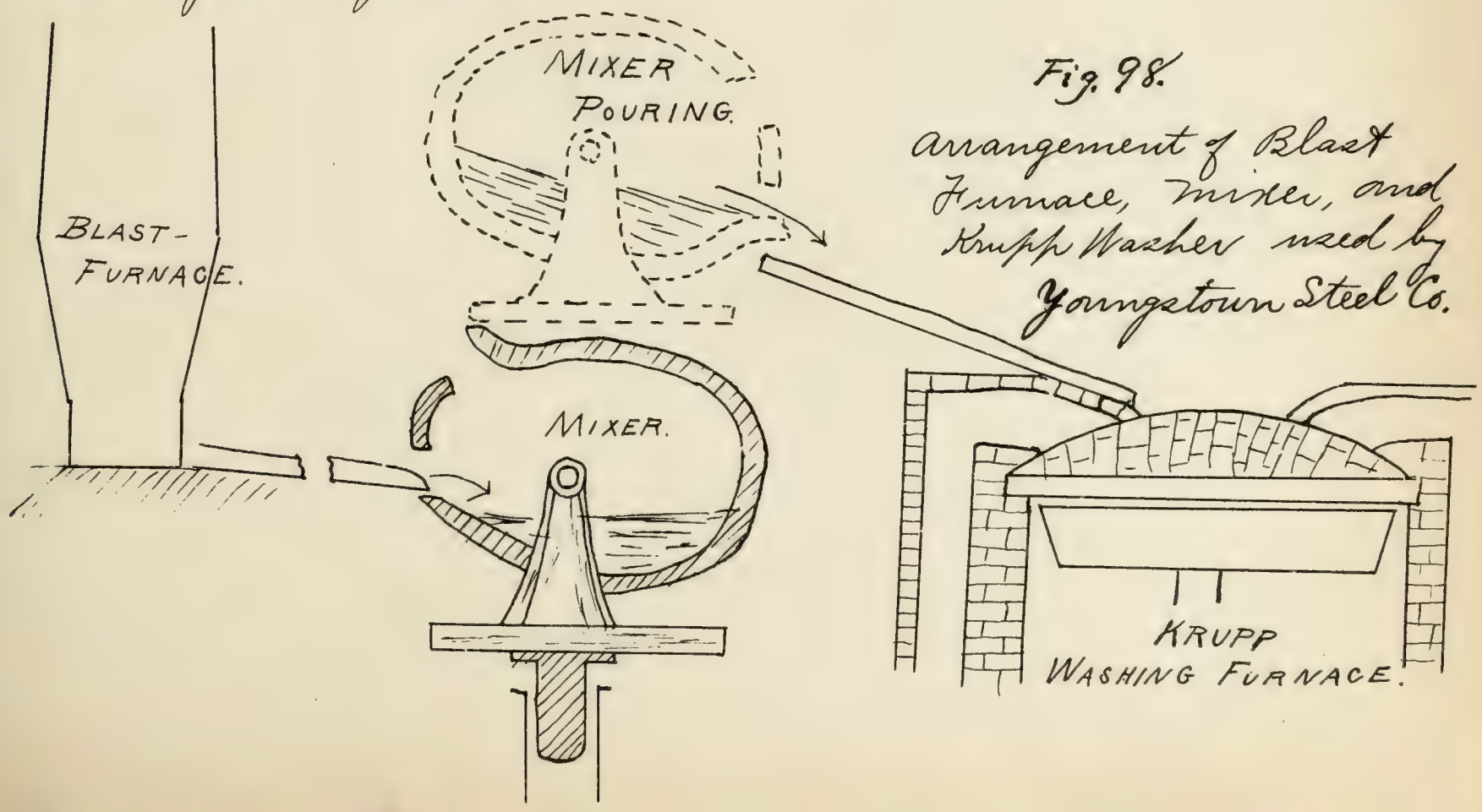
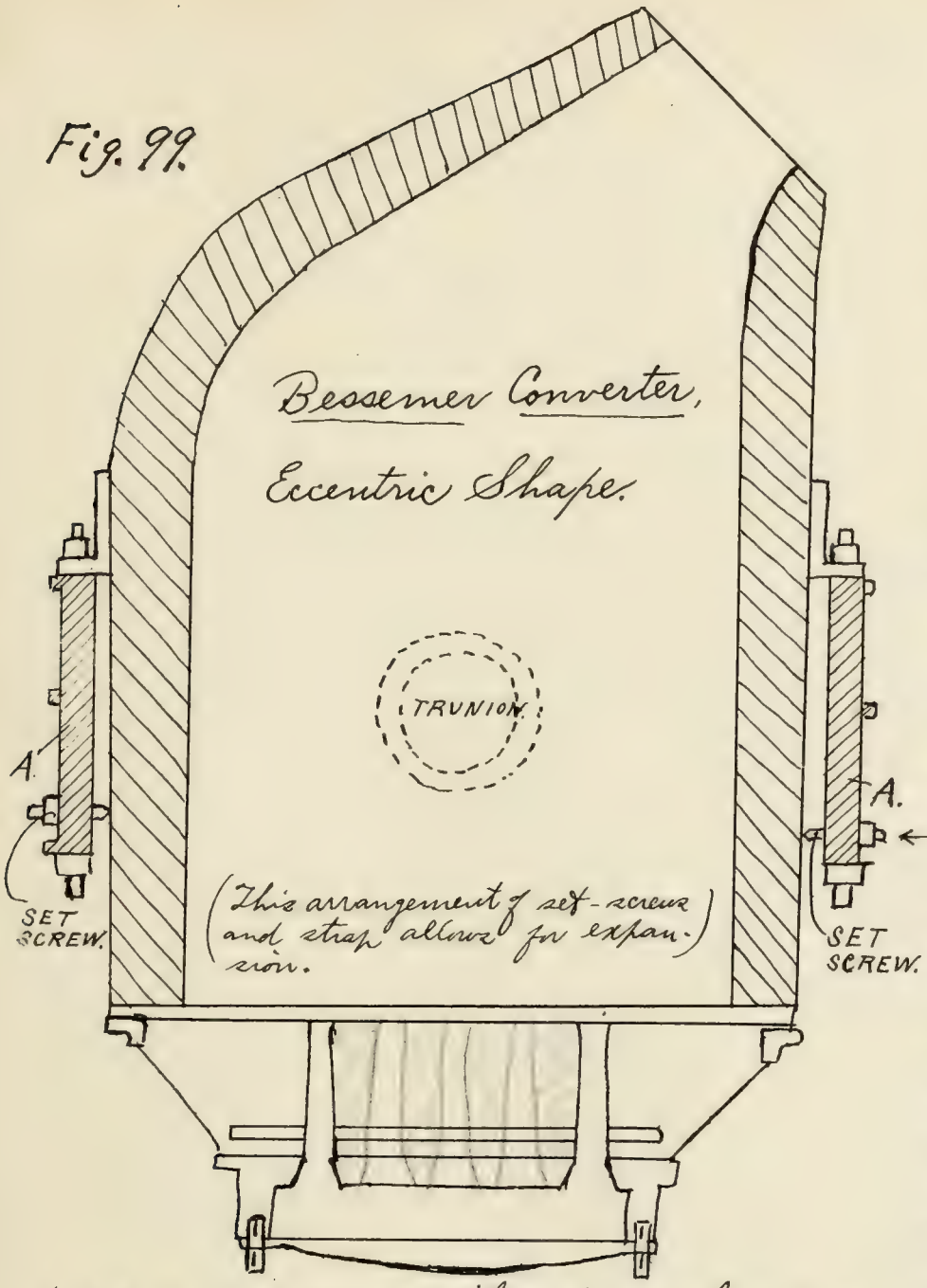


Fig. 98.
Arrangement of Blast Furnace, Mixer, and Krupp Washer used by Youngstown Steel Co.

The Bessemer Process.

Fig. 99.

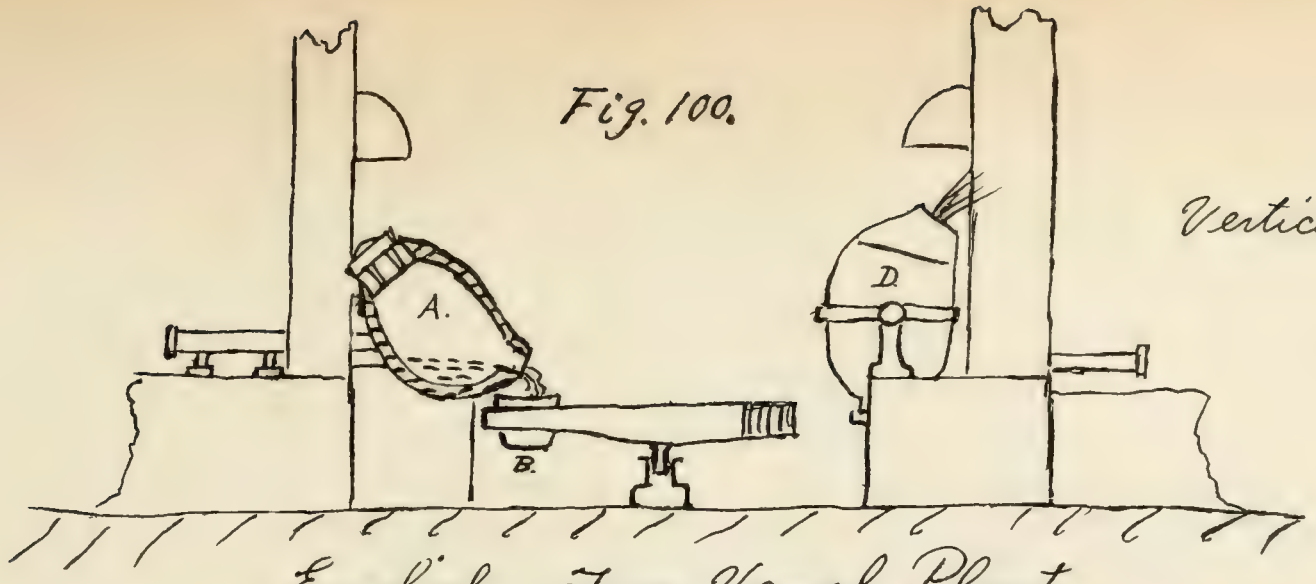


(A.A. is iron strap encircling the vessel, and to which the trunions are fastened.)

The Bessemer or Pneumatic Process converts pig iron into steel by blowing cold air through the molten pig. The oxygen of the blast burns out the foreign substances associated with the iron. These elements (mainly the Si.) furnish the fuel for producing the heat needed to keep the steel liquid while being cast. The blowing process is called converting, and the vessel in which it is done a converter, (see fig. 99.) The process is divided into two methods of working, (1.) Acid Bessemer, and (2) Basic Bessemer, or Thomas-Gilchrist process. The difference is based on the kind of lining of the converter. If it is siliceous (acid) no P. or S. is burned out, because Si can take away O from P_2O_5 leaving the P. free to combine again with the Fe. Therefore only pig having very small amounts of P. and S. can be used. With a lime- or magnesia-lined converter the P. can all be eliminated, and also most of the S. The heat needed is got from the burning of the Phosphorus, so that here only a high Phosphorus pig can be used.

In both processes the C., Si., and Mn. are burned out, leaving the bath in the chemical condition of molten wrought iron. This is next brought to the condition of steel by adding C. to it. Some Mn. also must be added to render it malleable (A. I. M. E., vol. X, p. 302). This is done by mixing into it molten spiegeleisen.

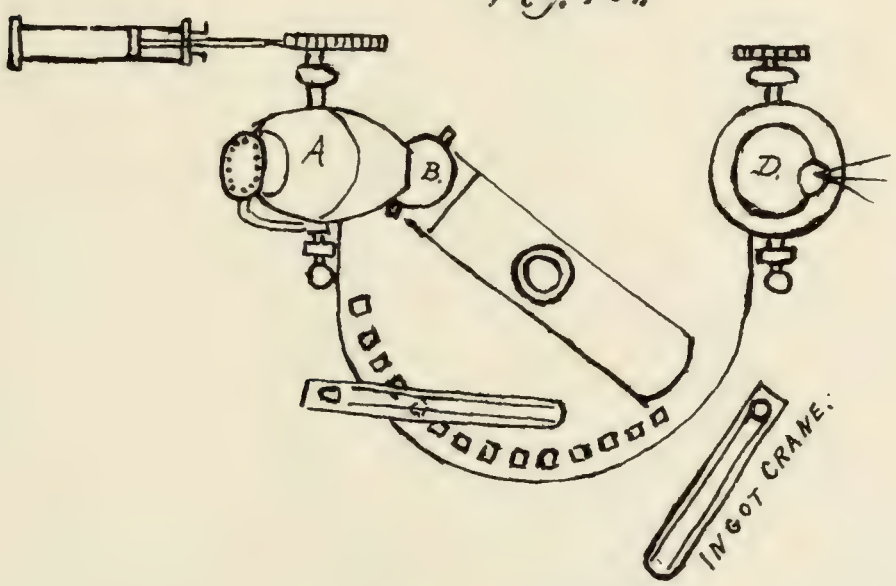
Fig. 100.



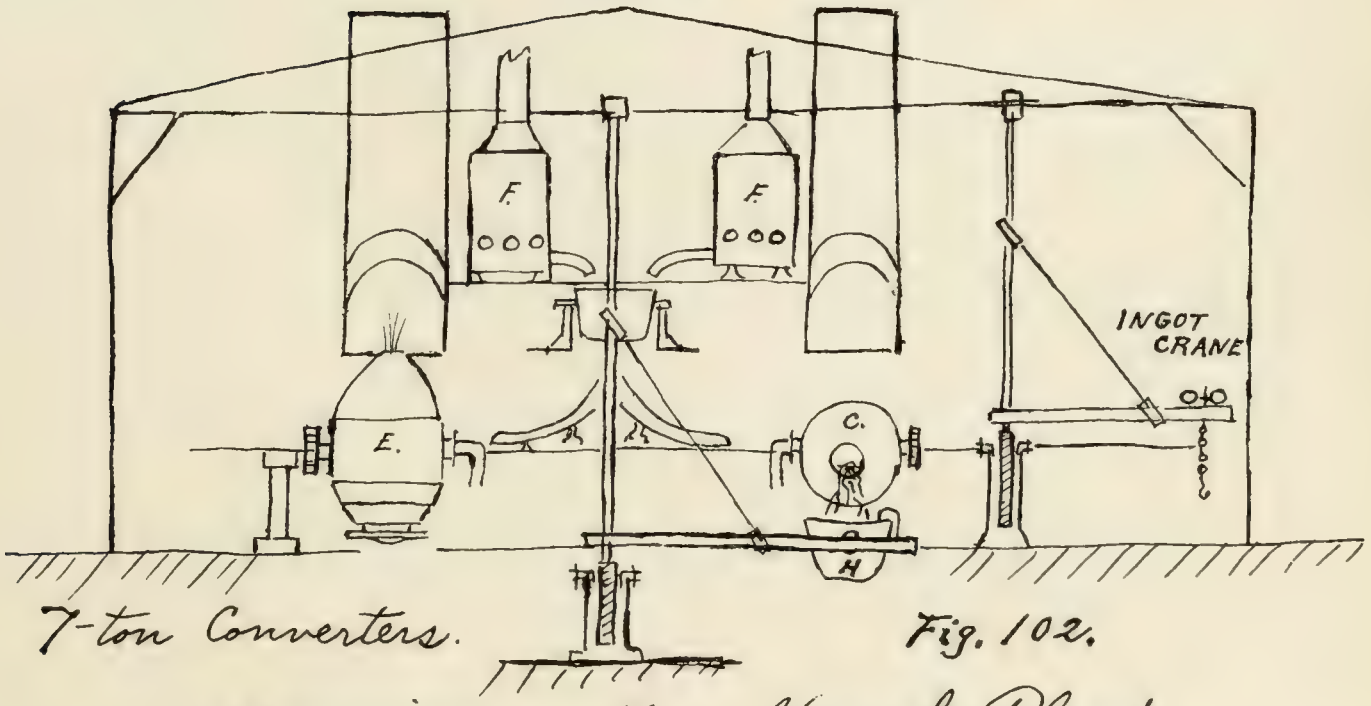
Vertical Section.

English, Two Vessel Plant.

Fig. 101.



Plan of English Two Vessel Plant.



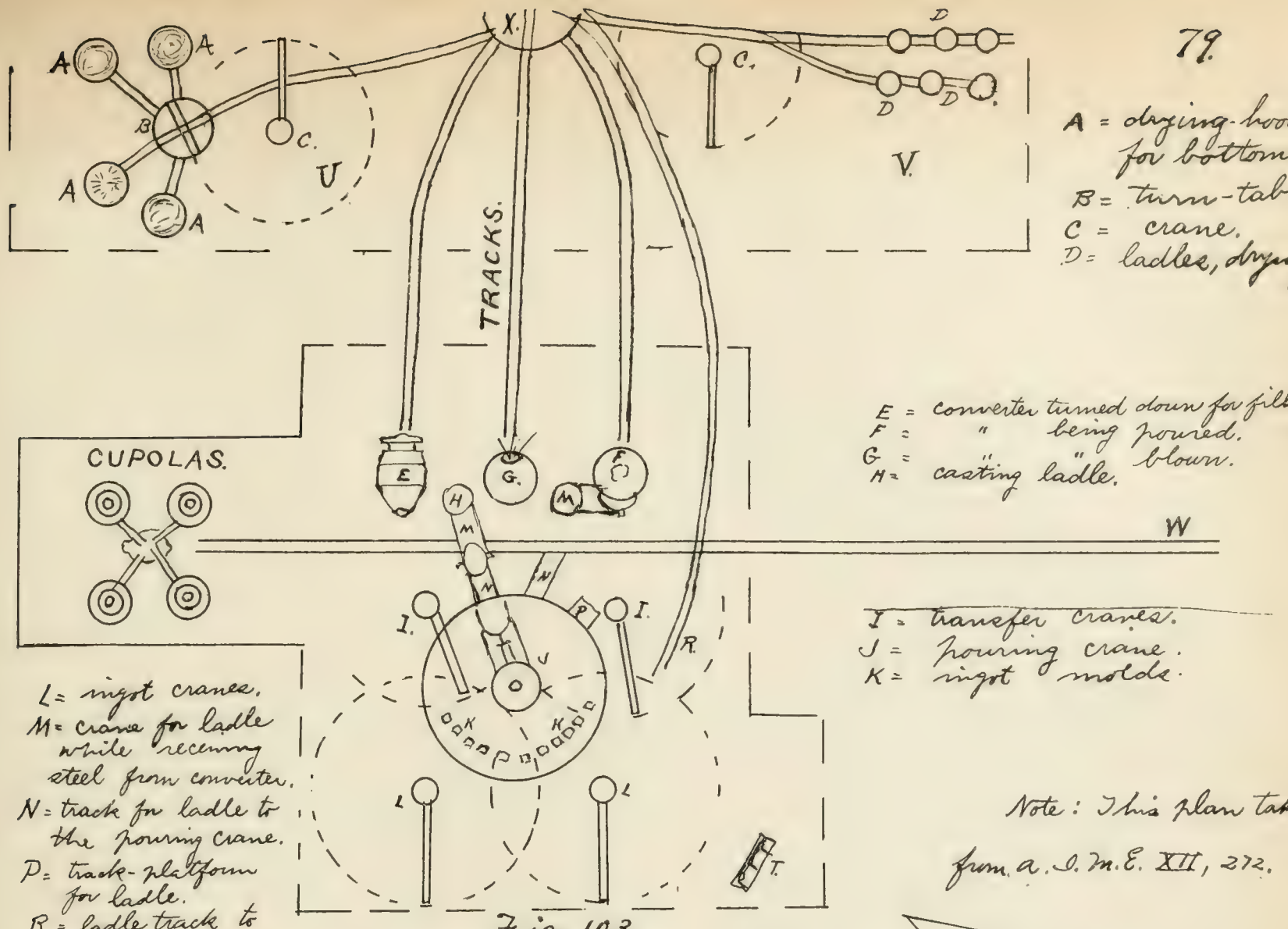
7-ton Converters.

Fig. 102.

American, Two Vessel Plant

General arrangement of Bessemer Plants.

A and C show position of converter while pouring the steel.
D " E " " " " " blowing a heat.
B " H are the ladles for receiving the steel from converters.
F " F are cupolas for melting the pig iron.



A = drying-hood for bottoms
B = turn-table.
C = crane.
D = ladles, drying.

E = converter turned down for filling.
F = " being poured.
G = " blown.
H = casting ladle.

I = transfer cranes.
J = pouring crane.
K = ingot molds.

L = ingot cranes.
M = crane for ladle while receiving steel from converter.
N = track for ladle to the pouring crane.
P = track-platform for ladle.
R = ladle track to repair shop.
T = "pulpit."
U = repair shop (for bottoms)
V = " " " ladles
W = direct metal tracks from blast furnace.
X = turntable.

Note: This plan taken from a. I. M. E. XII, 272.

Fig. 103.

3 Vessel Plant, with Casting Pit.
Illinois Steel Co.
10 ton Converters.

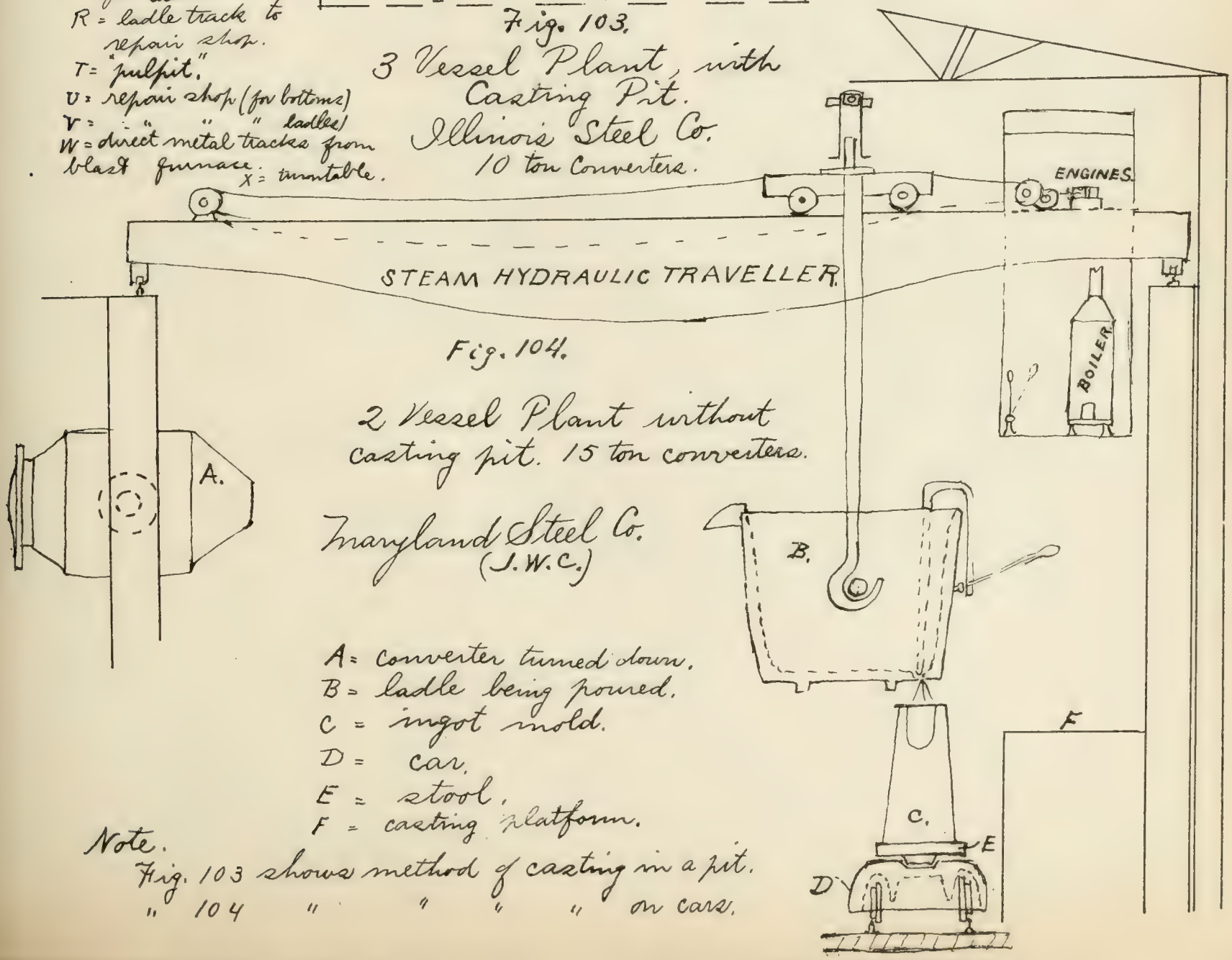


Fig. 104.

2 Vessel Plant without casting pit. 15 ton converters.

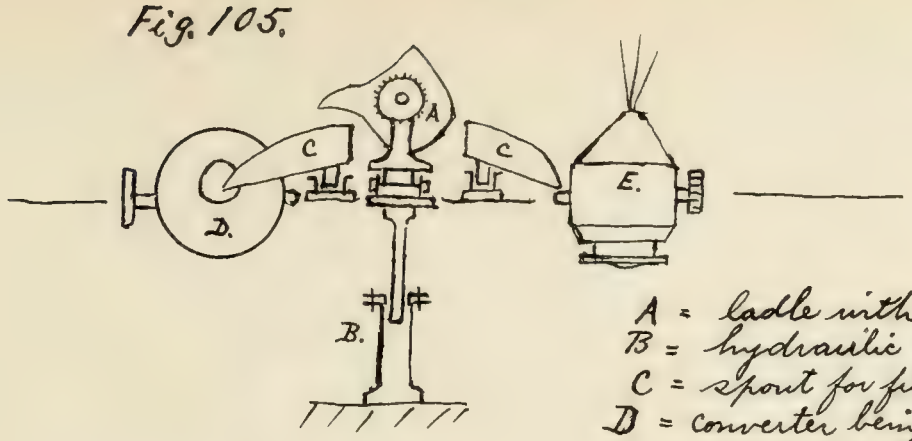
Maryland Steel Co.
(J.W.C.)

A = converter turned down.
B = ladle being poured.
C = ingot mold.
D = car.
E = stool.
F = casting platform.

Note.
Fig. 103 shows method of casting in a pit.
" 104 " " " " " on cars.

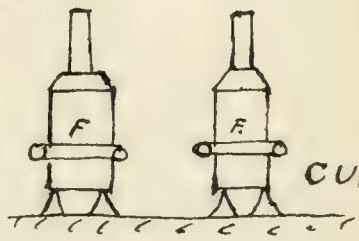
Charging the Converter.

Fig. 105.



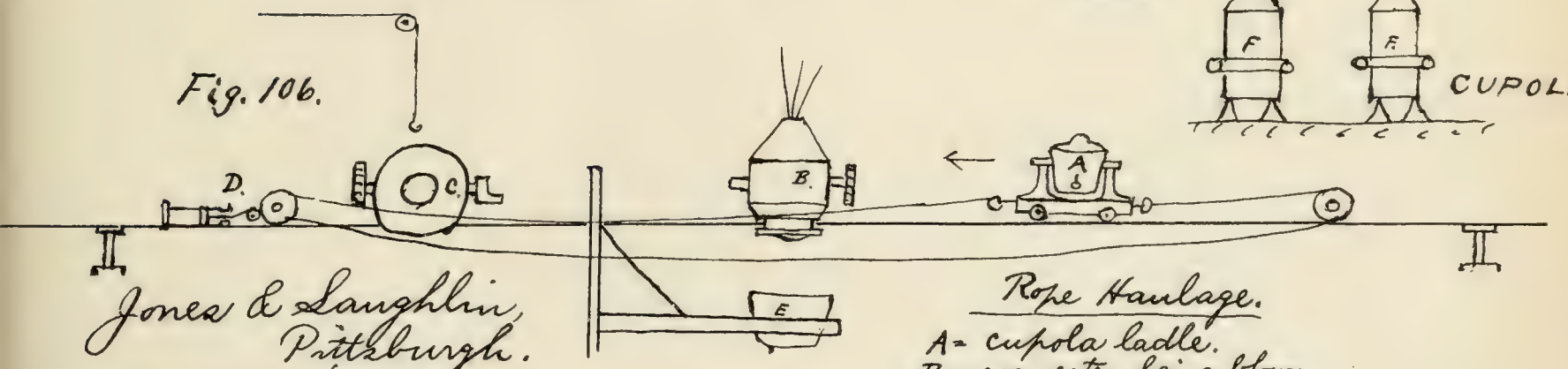
Locomotive and Hydraulic Lift.
Bethlehem Iron Co.,
Bethlehem, Pa.
(J.W.C.)

A = ladle with molten iron from cupola.
B = hydraulic lift.
C = spout for filling converter.
D = converter being filled.
E = " " blown.



CUPOLAS.

Fig. 106.



Jones & Laughlin,
Pittsburgh.
(J.W.C.)

Rope Haulage.

A = cupola ladle.
B = converter being blown.
C = " turned down for filling.
D = engine & drum for wire rope
E = casting ladle.
F = cupola.

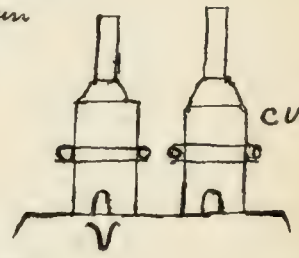
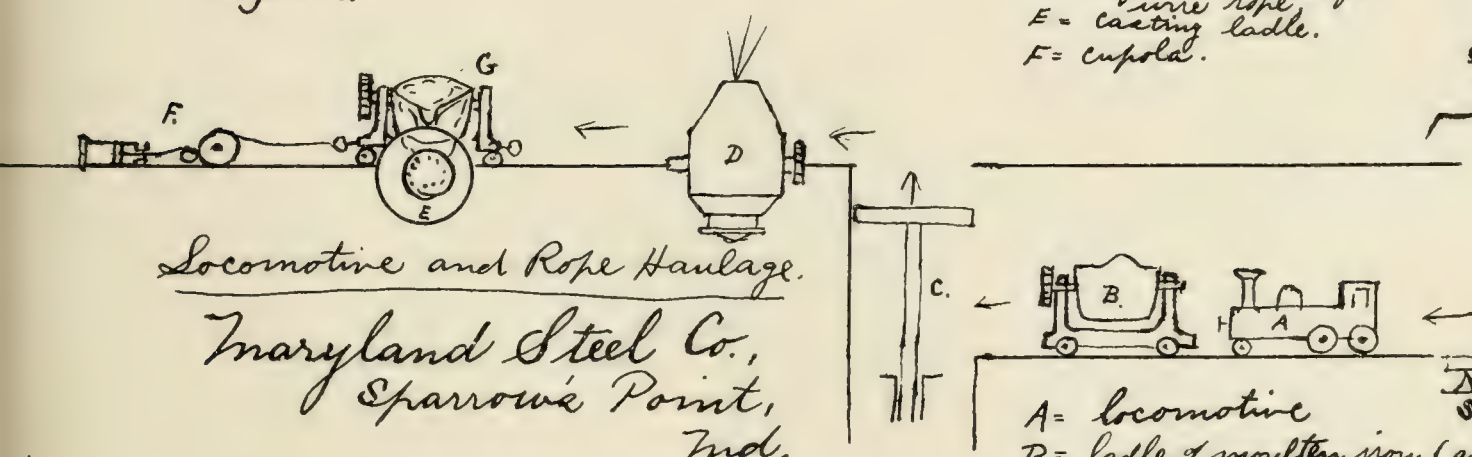


Fig. 107.

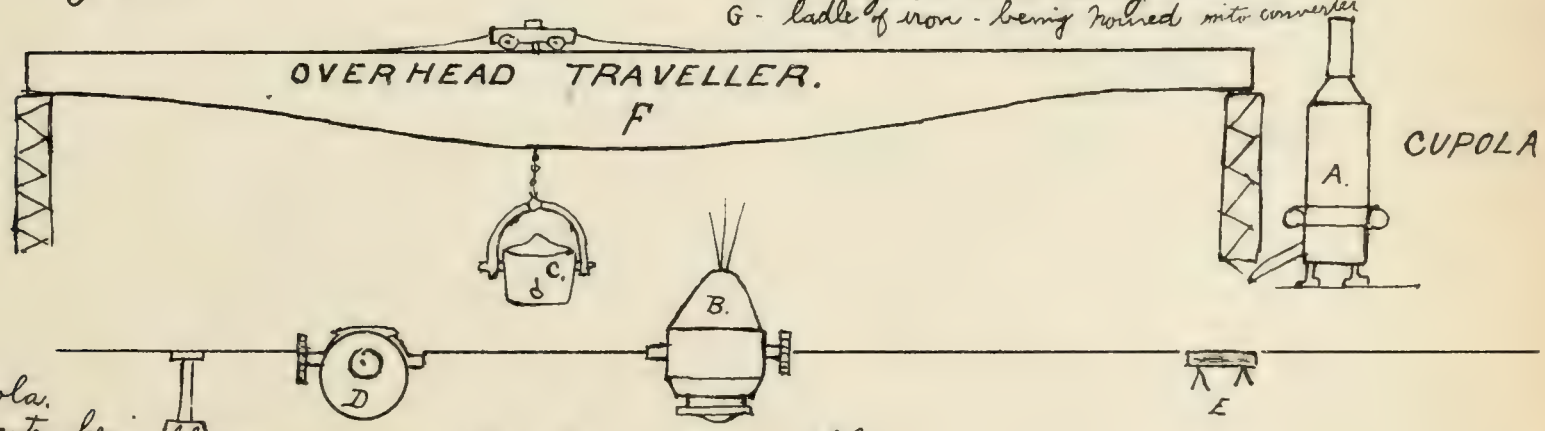


Locomotive and Rope Haulage.

Maryland Steel Co.,
Sparrows Point,
Md.

A = locomotive
B = ladle of moulten iron (a direct metal ladle)
C = hydraulic hoist.
D = converter being blown.
E = " " filled
F = engine & winding drum
G = ladle of iron being hoisted into converter

Fig. 108.

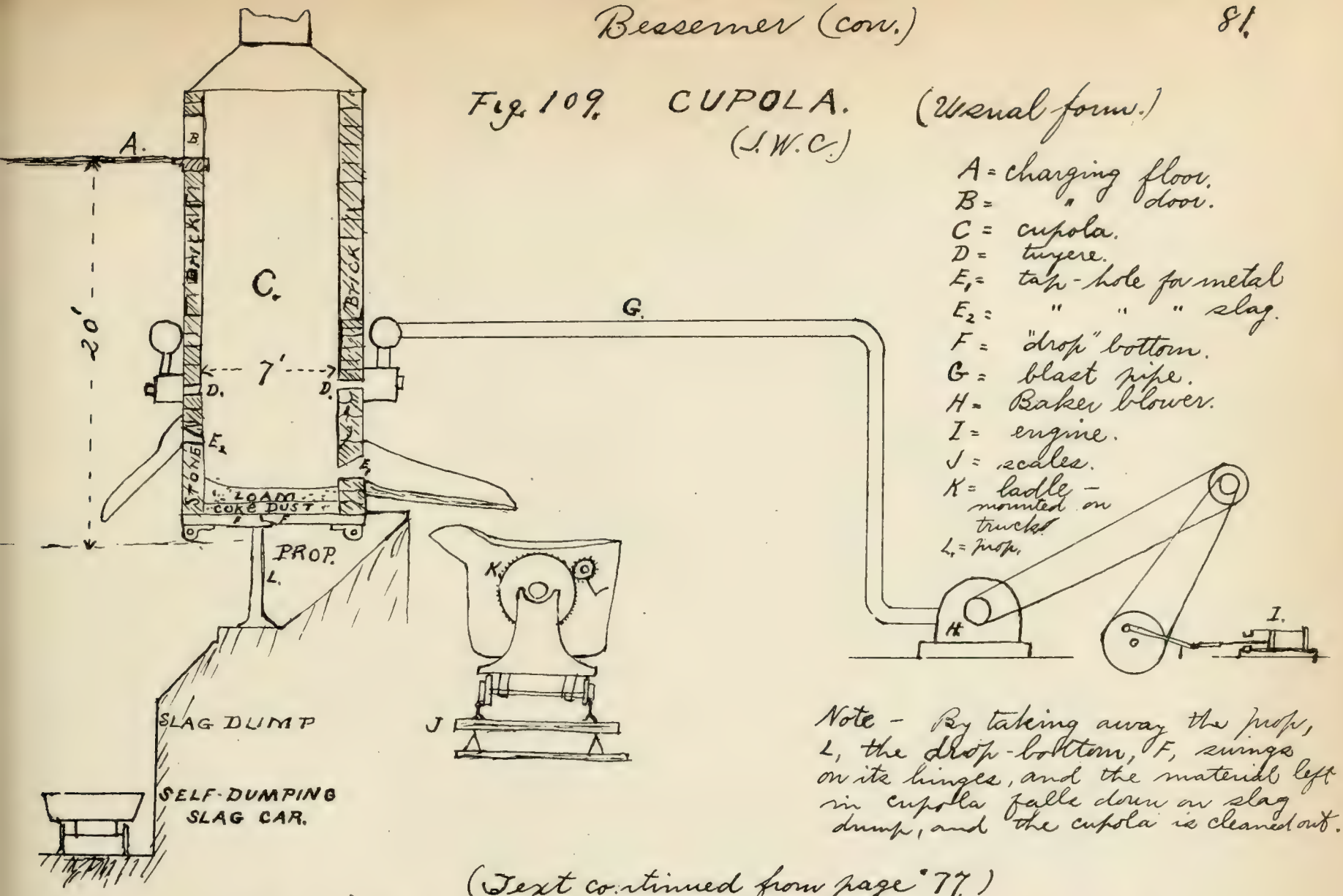


A = cupola.
B = converter being blown.
C = cupola ladle.
D = converter ready to be filled.
E = scales. F = overhead traveller.

Overhead Traveller.

Riverside Steel Co.,
Wheeling, W. Va.

Fig. 109. CUPOLA. (Usual form.)
(J.W.C.)



A = charging floor.
B = " door.
C = cupola.
D = tuyere.
E_1 = tap-hole for metal
E_2 = " " " slag.
F = "drop" bottom.
G = blast pipe.
H = Baker blower.
I = engine.
J = scales.
K = ladle — mounted on trucks.
L = prop.

Note — By taking away the prop, L, the drop-bottom, F, swings on its hinges, and the material left in cupola falls down on slag dump, and the cupola is cleaned out.

(Text continued from page 77.)

The steel is then poured from the converter into a ladle (see figs. 104, & 121.), and then from that into ingot molds.

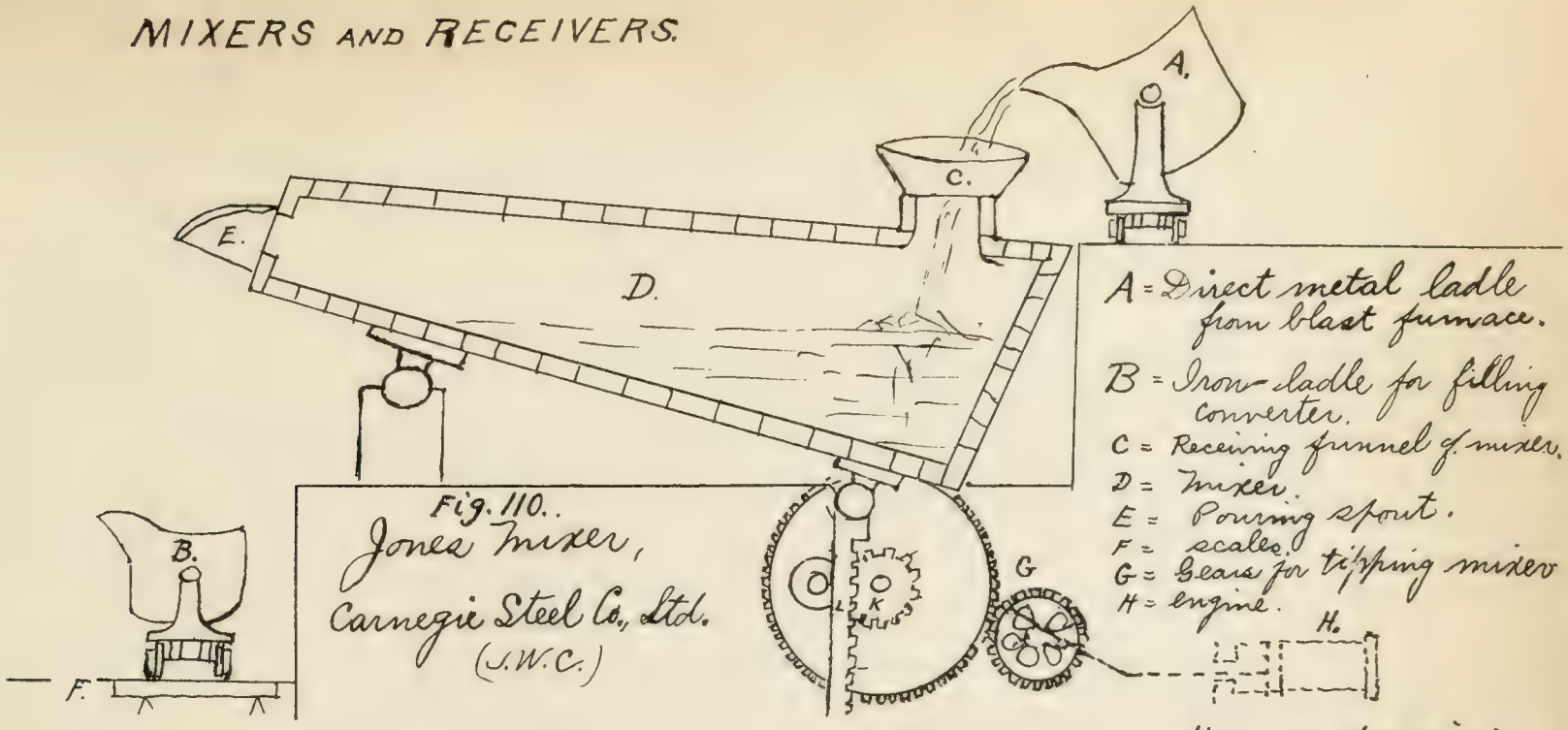
The molten iron for conversion is obtained in two ways; (1.) by melting pig iron in cupolas (fig. 109), called the Cupola process; and (2.) by taking the iron directly from the blast-furnace, called the Direct process.

Routine - Cupola Process.

The pig iron is usually loaded onto trucks, by hand, in the cupola stockyard, and from piles which have been sampled and analyzed. A mixture is made up having about this composition — Si. = 1.75%, Mn. = 0.75%, S = below 0.05%, P = below 0.10%, and Cu = below 0.10%. Cupola charges are weighed, hoisted to level of charging door, and dumped in. Inclined elevators fed at the bottom are sometimes used. Spiegeleisen is similarly sampled, analyzed, and melted down in smaller cupolas. Coke is analyzed for S.; only low sulphur coke is used (S = below 1.00%) because the pig absorbs S. from it in remelting.

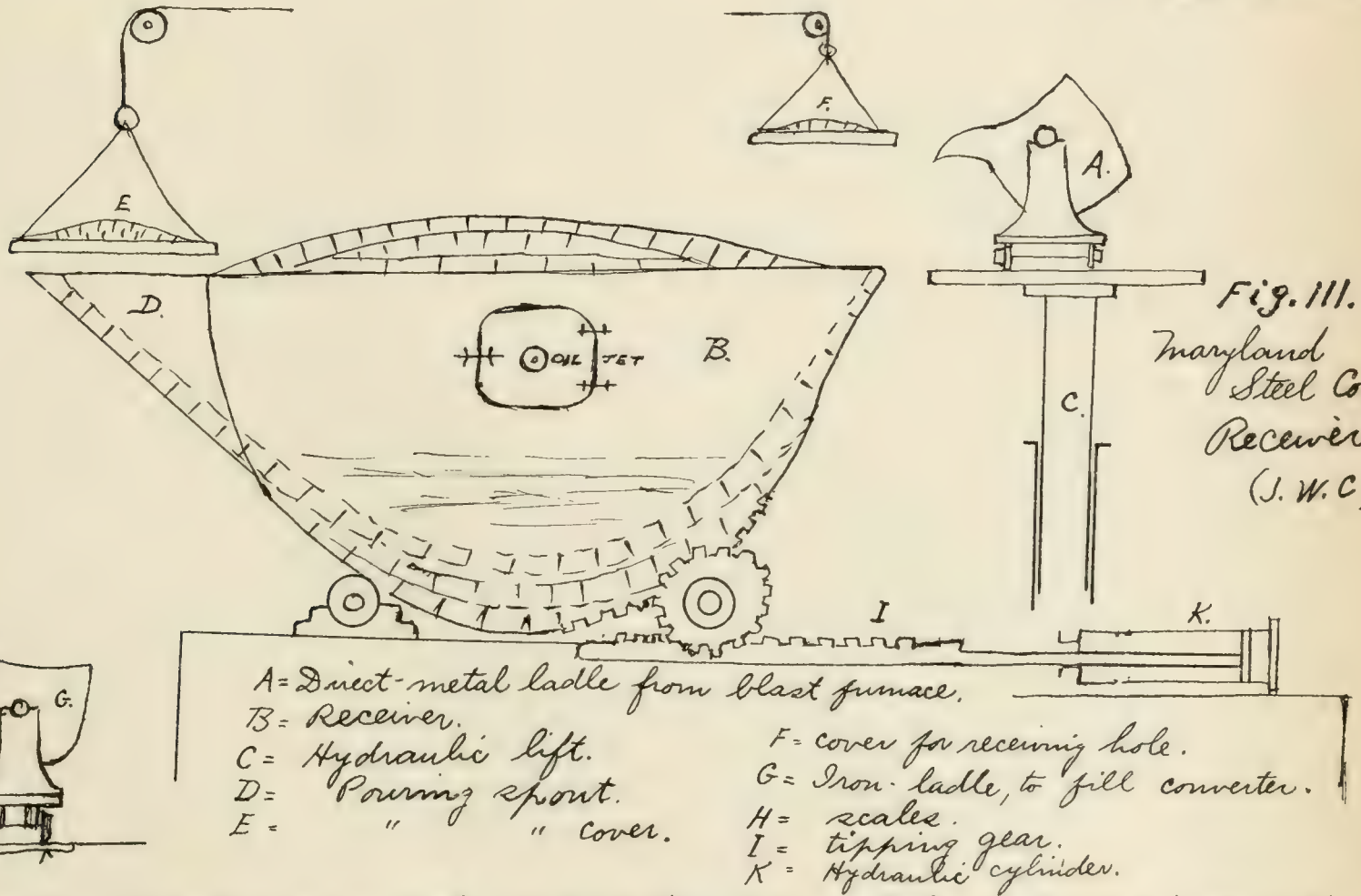
In starting a newly lined cupola it is first fired with wood, and then filled $\frac{2}{3}$ full of coke. Upon this the first charges are dumped. These must be higher in Si. than the regular mixture, beginning with Si. = 2.50% and gradually reducing, because

MIXERS AND RECEIVERS.



A = Direct metal ladle from blast furnace.
B = Iron ladle for filling converter.
C = Receiving funnel of mixer.
D = Mixer.
E = Pouring spout.
F = scales.
G = Gears for tipping mixer
H = engine.
K, L = Rack & pinion.

Fig. 110.
Jones Mixer,
Carnegie Steel Co., Ltd.
(J.W.C.)



A = Direct-metal ladle from blast furnace.
B = Receiver.
C = Hydraulic lift.
D = Pouring spout.
E = " " cover.
F = cover for receiving hole.
G = Iron ladle, to fill converter.
H = scales.
I = tipping gear.
K = Hydraulic cylinder.

Fig. 111.
Maryland Steel Co.,
Receiver.
(J.W.C.)

both the cupola and the converter are cold. The weight of coke is 8%; that of the limestone to flux the sand on the pig and the ash of the coke, is 3.5%. This fuel ratio is sometimes lower (A. I. M. E. XIX, p. 1150). If down to 6% there is danger of chilling the cupola.

A blast-pressure of 12 g. per sq. inch is put on, and in two hours the first charge is melted and is tapped out into a ladle standing on scales (fig. 109).

The increase of S. in remelting is greater with a close grained iron than with No. 1 open grained. It may increase

Fig. 112.

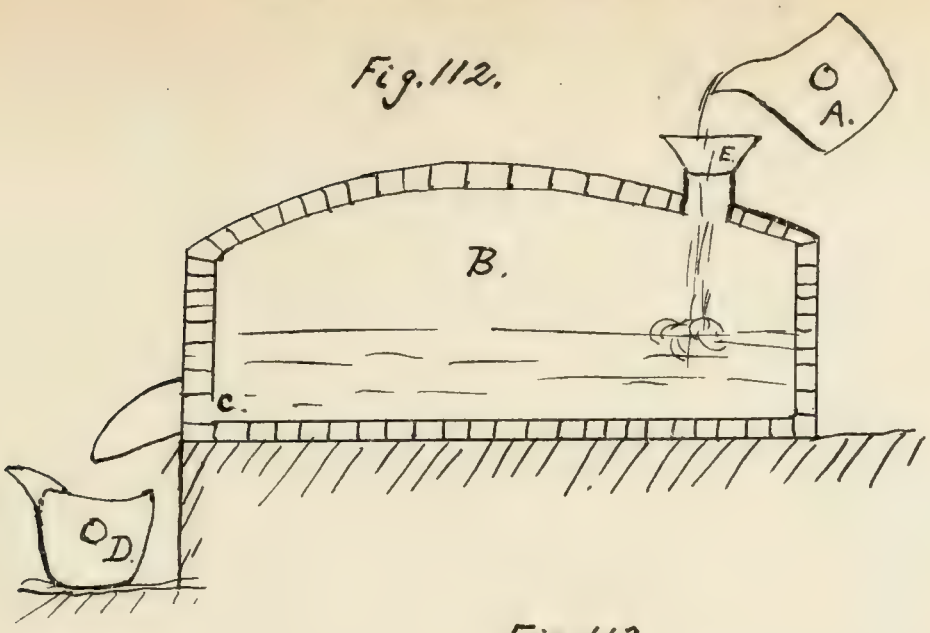


Fig. 112.
European Stationary Tank Receiver.

A = Direct-metal ladle from blast furnace.
B = Tank receiver.
C = Tap hole.
D = Iron ladle for filling the converter.
E = Receiving funnel.

Fig. 113.

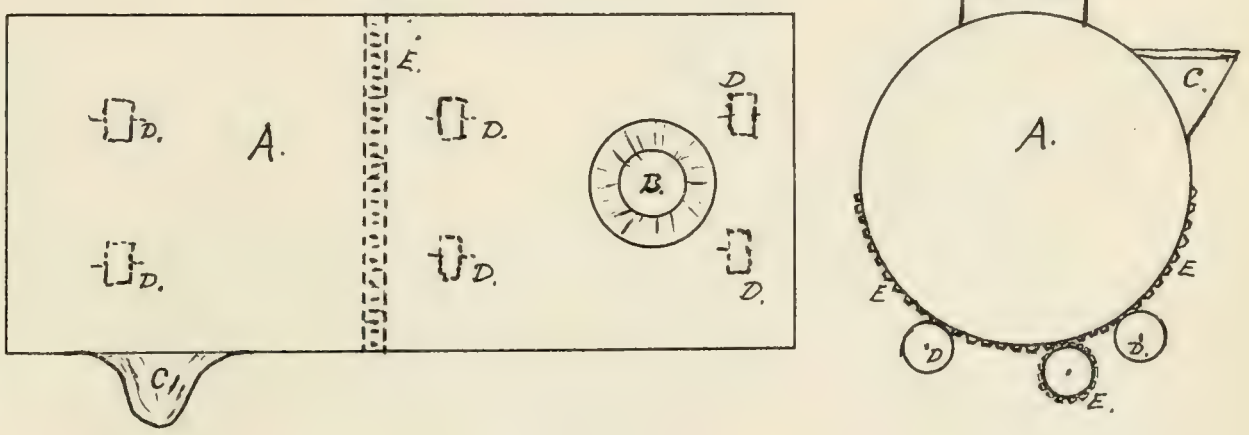


Fig. 113.
Illinois Steel Co., Mixer. (R.H.R.)

A = Cylinder mixer.
B = Receiving funnel.
C = Pouring spout.
D = Friction rollers.
E = Rack & pinion.

from .01% in the pig to .06% in the steel.

Pieces of steel scrap can also be melted in mixture with the pig iron, provided the total Si. in the mixture averages enough to give the heat needed in the converter. Some Si. is burned out in the cupola, so that the percentage is reduced by about .50%. There must usually be from 1.00 to 1.50% Si present when the iron goes into the converter. This is effected somewhat by the sensible heat of the iron — if this is low, from cold melting in the cupola while using a low fuel ratio, the Si. must be higher to make up the difference.

Direct Process.

In ordinary coke blast-furnace practice successive casts vary too much in Si. and S. to allow of taking the metal as it flows from the furnace into ladles and from them into the converter., and blowing it at once. It is therefore poured first into large reservoirs or mixers (or "receivers" figs. 110-113), the casts from different furnaces being mixed together. In Swedish practice, however, where a number of small charcoal furnaces are used, the product is regular enough for the iron to be blown direct

Fig. 114.

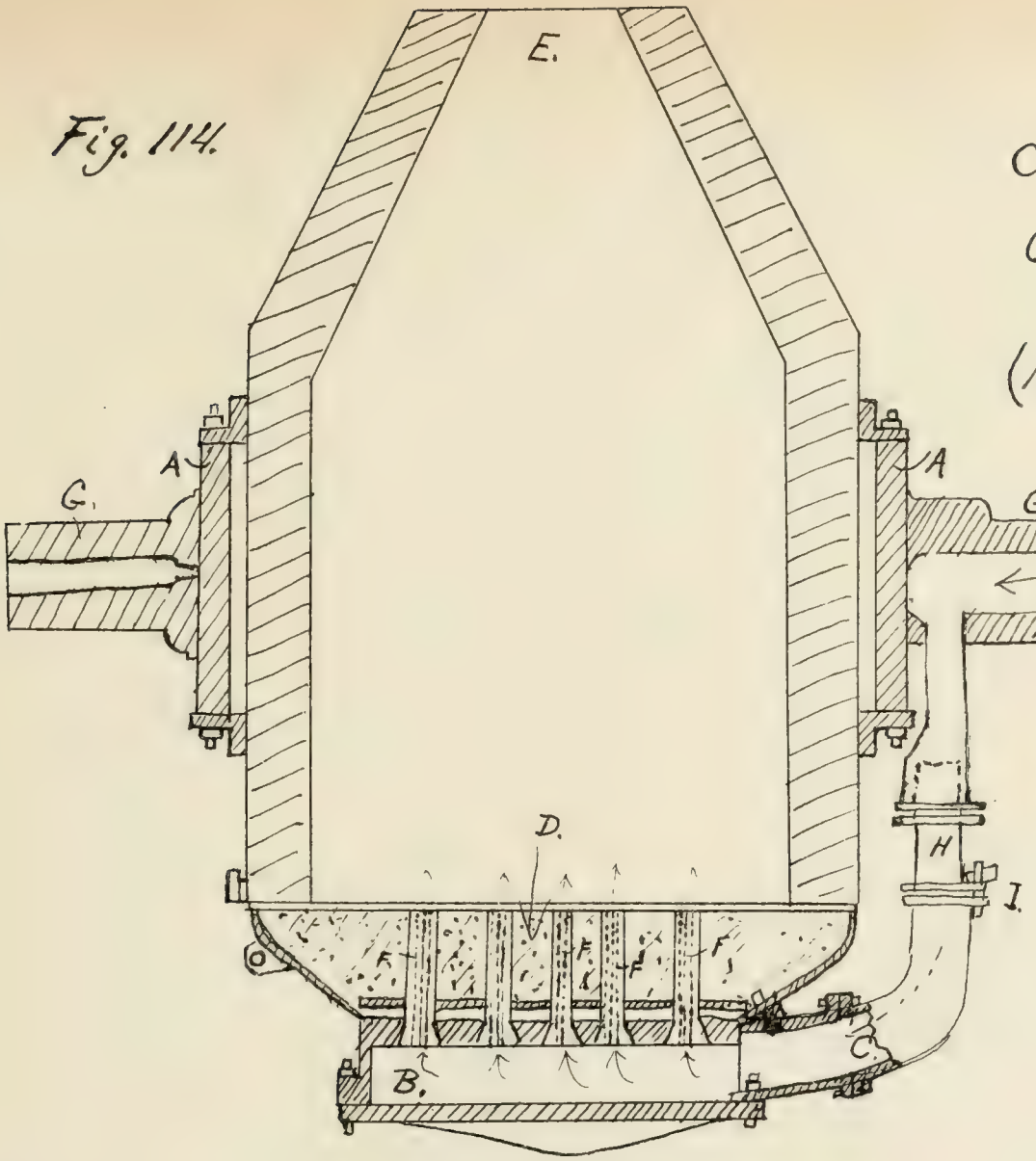


Fig. 114.

CONCENTRIC.

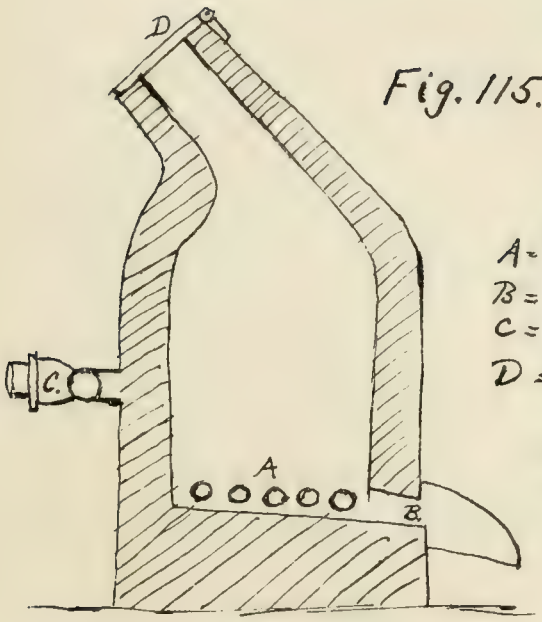
CONVERTER.

12 to 15 tons.

(Howe "Met. of Steel," p. 346)

A = Trunnion-ring.
B = wind box.
C = Wind-pipe.
D = Bottom.
E = Nose.
F = tuyeres.
G = trunions.
H = expansion joint.
I = flange unions.
J = rotary slip joint.

Fig. 115.



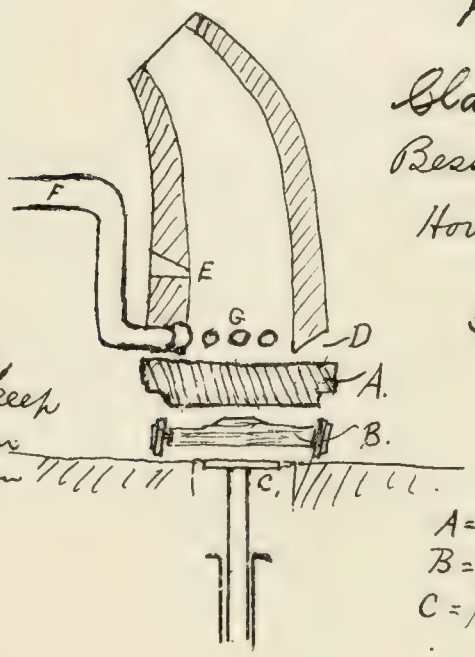
A = tuyeres.
B = tap-hole.
C = blast pipe.
D = Cover to keep vessel from cooling between "blows".

Old Fixed Swedish Converter.

Jeans, "Steel, its Hist., Mfg. & Uses", p. 373.

capacity = about 1 1/3 tons (p. 289)

Fig. 116.



Clapp-Griffiths Bessemer Converter.

Howe, "Met. of Steel", p. 356.

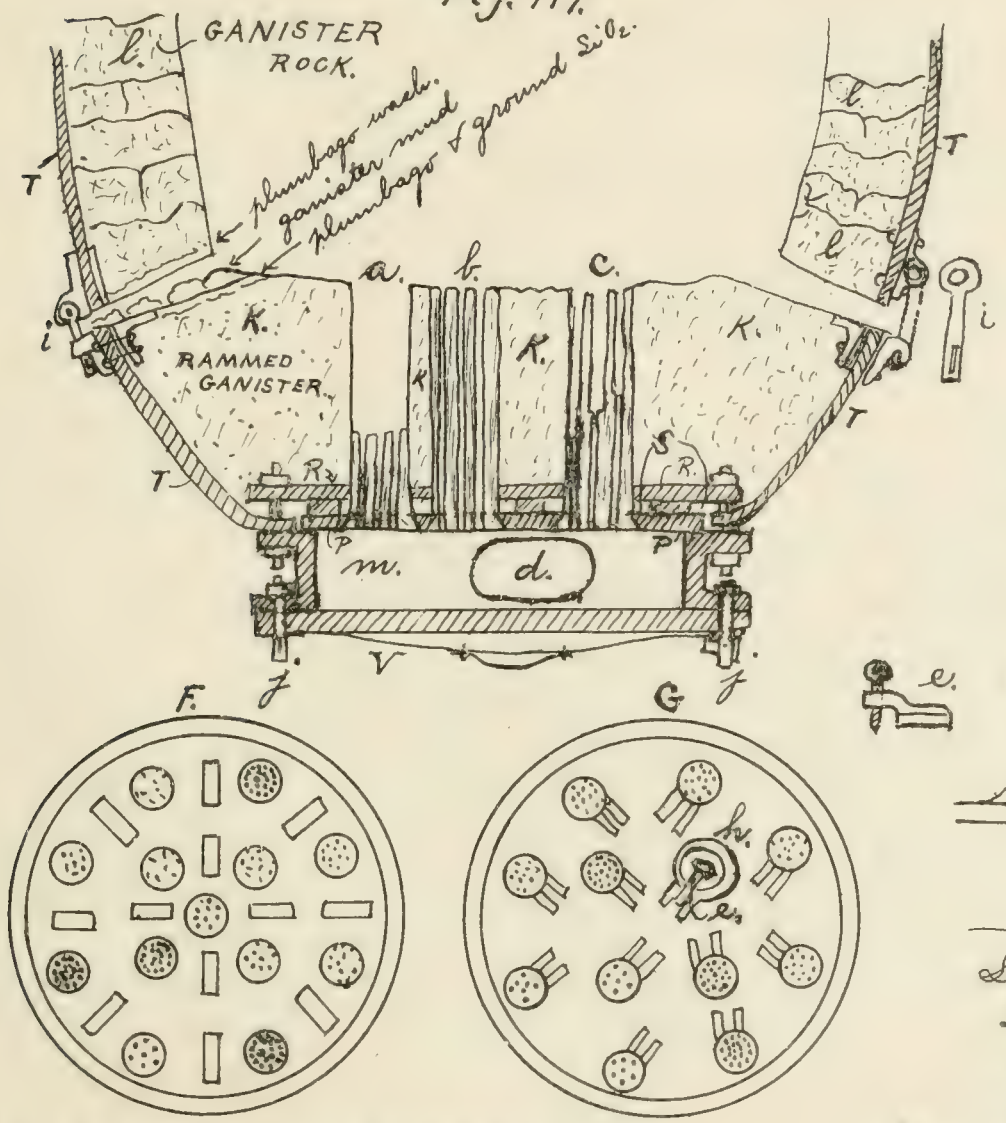
3 ton converter.

A = Bottom.
B = Bottom car.
C = Hydraulic bottom-jack.
D = Tap hole.
E = Slag-tap, where slag runs out during the boil.
F = blast pipe.
G = tuyeres.

without using mixers. From samples of each cast run into a mixer the average Si. and S. is obtained before it is blown, as a guide to the blower. The iron is taken from the mixer as wanted and blown the same as cupola iron. Some S. is eliminated by the iron standing in the mixer a long time, but no Si. nor C. goes off. To prevent the iron from chilling over the top, an oil jet is blown in with steam. The sensible heat of direct iron is higher than cupola iron so that less Si. is needed in it. From 0.75% to 1.00% Si. will blow hot enough.

CONVERTER BOTTOM.

Fig. 117.



a. = tuyere going bodily.
b. = good tuyere, wearing no faster than bottom.
c. = tuyere "boring", or going by "piping."
d. = blast admission to wind box.
e. = clamp for blanking bad tuyere.
F = bottom seen through mouth of converter.
G. = bottom seen from wind box.
h. = a blanked tuyere, as seen from wind box.

The tuyeres have either 7 or 19 holes, $\frac{5}{16}$" to $\frac{5}{8}$" diam.

Large converters (15 tons) have 25 tuyeres - smaller ones have 12.

i = key-bolts for attaching bottom.
J = " " " " bonnet plate.
K = rammed ganister.
l = ganister rock.
m = wind box.
N = tuyere.

P = tuyere plate.
R = false plate.
S = port-holes.
T = plate-iron shell.
V = bonnet plate.

Blowing.

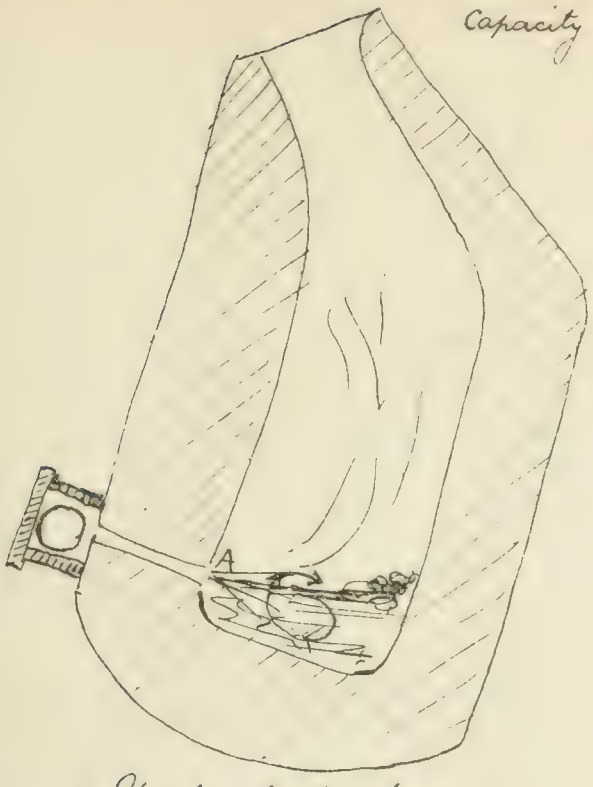
The joint between the converter and the bottom (fig. 117) is made with a mixture of ground ganister rock

The Robert Converter.

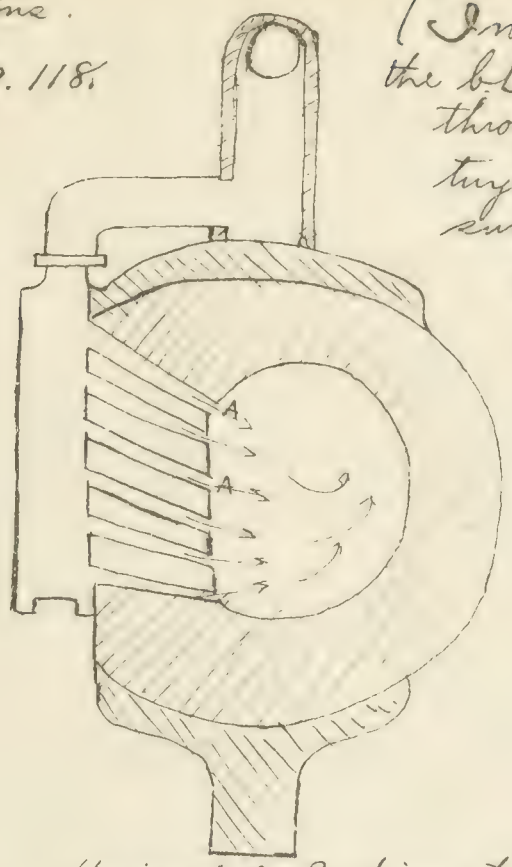
(Howe, "Met. of Steel", p. 357)

Capacity, 2-3 tons.

Fig. 118.



Vertical Section.



Horizontal Section at Tuyeres.

(In the Robert converter the blast is introduced through horizontal tuyeres near upper surface of the metal. The vessel is rotary. It is tipped during first part of blow so that the tuyeres almost emerge from bath. As blow proceeds the level of tuyeres is gradually lowered.)

(and the temperature of the metal is lowered minimizing the percent of Si; and of the low silicon (a flinty sandstone) and fire-clay, with a parting of plumbago, and is rammed tight from the outside. The converter is fired with wood and coal with a gentle blast until the lining is yellow hot. Then the iron from the cupola or the mixer is poured in, the blast turned on, and the converter "turned up" to a vertical position (see figs. 105-6-7-8.) The blast rushes up through the bath and Si begins at once to burn, raising the temperature until high enough to start the Carbon burning; Si is then nearly all out. Carbon burns to CO. By the appearance of the flame the blower judges whether there will be heat enough to keep the steel liquid during casting. If not, the converter is turned down half way and the blast directed from the upper tuyeres. This increases the heat of the converter, If there be too much Si., cold steel scrap is shot into the nose of the converter from an overhead platform. The scrap is free from Si. and so dilutes that in the converter. Steam is sometimes used to cool down a charge; a jet is admitted to the blast pipe, and is controlled by a valve. If made too hot, the steel will not roll well (A. I. M. E. vol. XIV, p. 84).

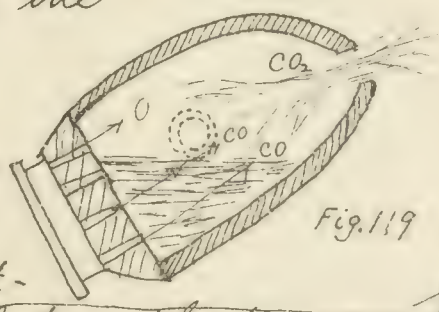


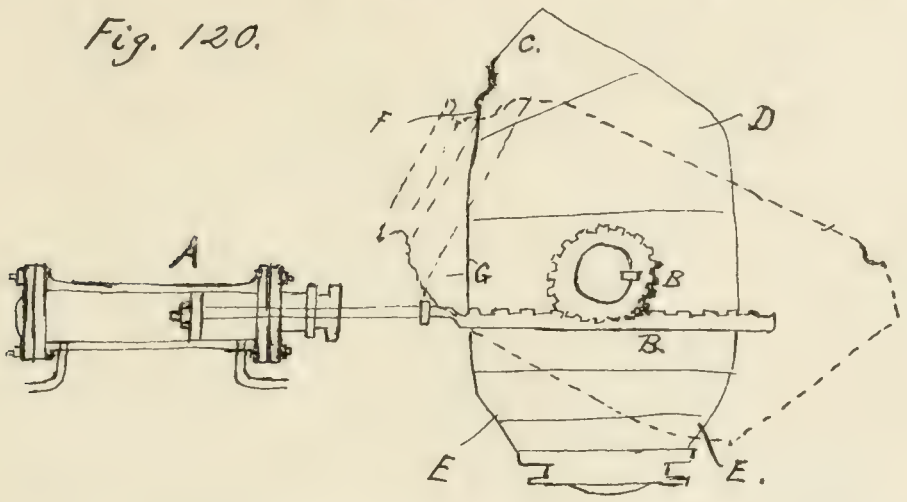
Fig. 119

After blowing 12 minutes with a blast pressure of 30 lbs. the C. is reduced to .05% when the flame loses color

Blowing (con.)

and becomes shorter, and an instant later becomes fringed with brown smoke (Fe_2O_3). The converter is turned down, and is ready for the spiegel. If soft steel is being

Fig. 120.



Tipping Gear.
(Howe "Met. of Steel," p. 349.)

A = hydraulic cylinder.
B = rack and pinion.
C = "nose" of converter
D = "belly" " "
E = "shoulder" " "
F = "breast" " "
G = "back" " "

made ferromanganese is used instead. This has Mn = 80% and C = 6.5%. The soft steel requires Mn. in larger proportion to carbon than rail steel does. The spiegel contains 20% of Mn. and 4.5% of C. The amount of spiegel added is about 10% of the weight of the converter charge; of ferro. from .8 to 1.0%, for soft steels. Ferro. is not remelted, but after being broken in pieces the size of an egg and heated red hot in a simple form of reverberatory, it is shoveled into the casting ladle while the converter is being emptied. The loss of Mn. in remelting spiegel is about 10%, in recarburizing 30%. The loss of C. is about 20%. The amount of Si. in the spiegel will affect these losses because some of the loss will fall upon it. When Si. is high the loss of Mn. and C. is less. Mn. and Si. unite with the FeO always found in the bath.

Most of the slag remains in the converter after the steel has been poured out, unless it is very thin from having much Mn., lime, or alumina, or from being too hot. It is dumped into a car standing under the converter. The loss, or wastage, is 10-12%. The bottom is examined and any bad tuyeres are plugged with plumbago mud and blanked (see "h," fig. 117.) Bottoms last from 18 to 25 "blows" (A. I. M. E. XII, p. 254). Conditions injurious to the life of the bottom are —— low blast; cold or viscous iron; great depth of metal over tuyeres; dampness of the rammed material; tuyeres not burned hard enough; too much Al_2O_3 and Fe_2O_3 in the ganister mixture.

In making up bottoms, the tuyeres are clamped

into the tuyere plate (fig. 117.), and a slightly moist mixture of ground ganister and fire-clay (in the proportion of 2 parts ganister to 1 part clay) is rammed around them in thin layers with hot rammers.

Analysis of Ganister.

SiO_2 = 98.% $Fe_2O_3 + Al_2O_3$ = 1.0% $CaO + MgO$ = 0.0%

Fireclay.

SiO_2 = 86 %. Al_2O_3 = 10% alkalies, etc = 4%

Long fire-brick (tile) are set on end at intervals between the tuyeres and reaching through all the layers to bind the whole bottom together. The bottom is dried four days in a drying oven (fig. 124) If not absolutely dry it is useless. Twelve bottoms are always kept on hand drying. Brick bottoms are also used in which the rammed material is replaced by long brick, shaped to fit in between the tuyeres. The difficulty with them is to get tight joints.

The tuyeres are 24" to 28" long and have 19 holes $\frac{5}{16}$" diameter or else 7 holes $\frac{3}{8}$" diam. (see fig. 117.)

"Pin-bottoms" are sometimes used. They have no brick tuyeres, but are made by ramming ganister mixture around long iron pins which are afterwards drawn out, leaving the holes for the blast.

Converter Lining.

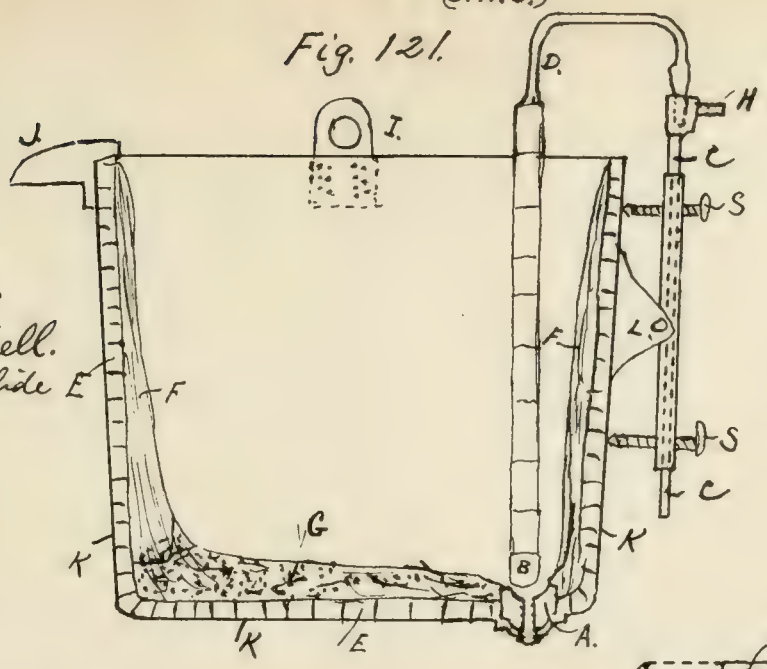
Converters are lined with blocks of ganister, or any refractory sandstone, built in like a wall, and faced and jointed with ganister mud. Pure ganister gives trouble from its expanding when heated. If too low in SiO_2 the lining will melt out rapidly. Linings last for months unless Mn. in the pig iron treated is above 1.50%, when it cuts out. If the iron has much liney slag mixed with it, the lime will also rapidly flux the SiO_2 of the lining. If the bases are very low, and the slag thick, the lining builds up and has to be cut out at intervals. The nose section is lined either with shaped brick or cut stone, and lasts only a week.

The Casting Ladle.

The casting ladle (fig. 121) is lined first with

Casting Ladle.
(J.W.C.)

Fig. 121.



I = Ear.
J = Slag spout.
K = plate iron shell.
L = fastening of slide & ladle.

Fig. 121.
Section of Casting Ladle.
A = Nozzle.
B = Plumba end of stopper.
C = Stopper slide
D = Stopper rod.
E = Fire-brick lining.
F = Loam lining.
G = Ganister "
H = Fastening for operating lever.

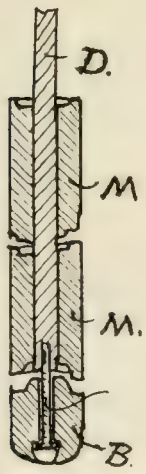
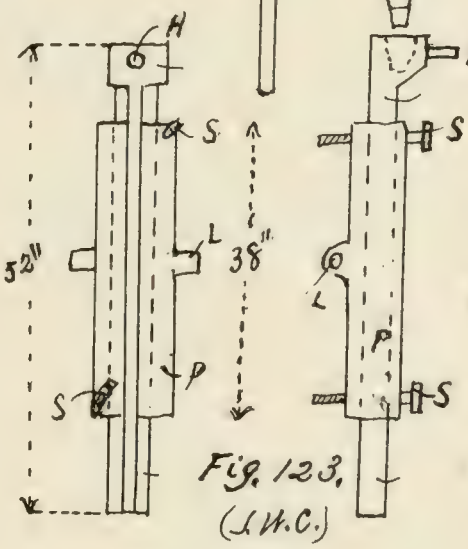
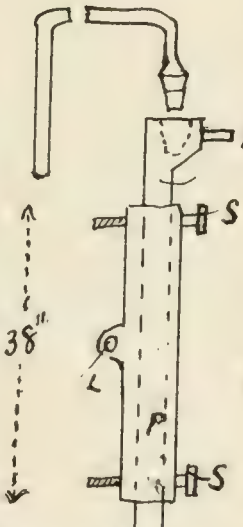


Fig. 122.
(J.W.C.)

Stopper and Rod.
B = Plumbago end.
M = Fire-brick sleeve.
D. = Stopper rod.
N. = T bolt to fasten end of the rod (C).



Stopper Slide.
(Wellman.)



C = The stopper slide
P = Groove for slide.
H = Fastening for operating handle.
S. = Set screws
L. = Fastening of slide to the ladle so as to permit adjustment of stopper.

a course of brick against the plate-iron shell, and upon this is pounded moist loam. The bottom is made of rammed ganister mixture. The pouring hole is fitted with a cylindrical brick ("nozzle", see A. fig. 121.) having a hole 2" to 4" diam., and a bowl shaped seat upon which the stopper sets (fig. 121). The lining of the casting ladle lasts 40 "blows"; a new "nozzle" and ~~stopper~~ is put in about every fourth "blow". The quality of the ingot depends much upon how the steel is poured through this hole into the ingot molds. If the stream is not central, or if it spatters in running in the ingot will be defective.

Molds and Ingots.

The molds last 90 operations. The composition of the iron for the molds is, Si = 1.70%; P = .10%; S. = .05%, Mn. = .75%. Either higher or lower Si. is injurious. The mold must be hard to withstand the

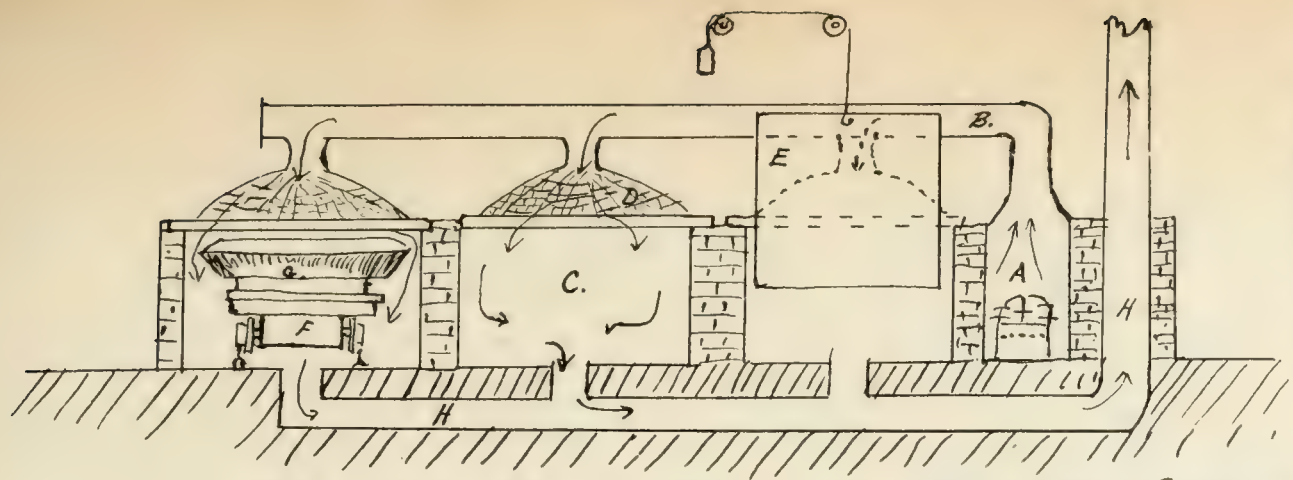


Fig. 124.

A = Fire place.
B = Flue
C = oven.
D = roof of oven.
E = door " "
F = bottom - car.
G = converter bottom.
H = flue to stack.

Fig. 124. Drying Ovens for Converter Bottoms.
Maryland Steel Co. (J.W.C.)

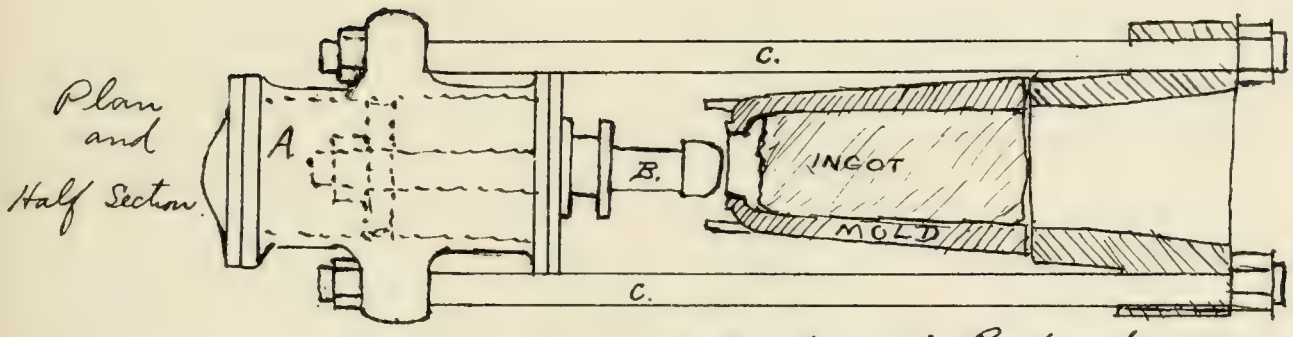


Fig. 125.
Horizontal.
Ingot Extractor.

A = Hydraulic cylinder.
B = Plunger.
C = 6" tie rods.

Fig. 125. Horizontal Ingot Extractor.
(J.W.C.)

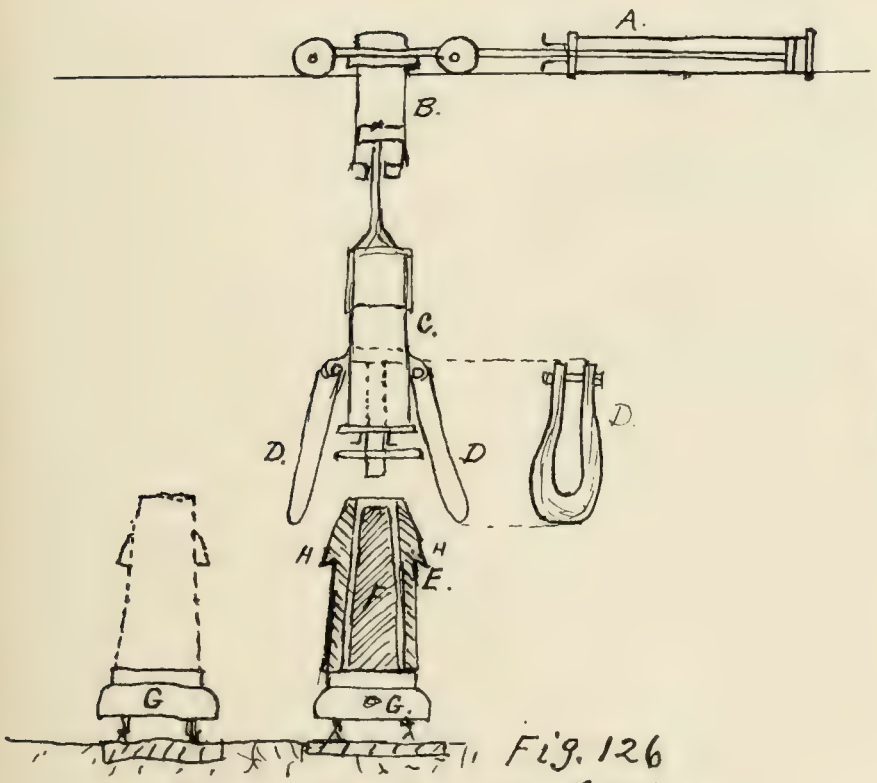


Fig. 126

Vertical Ingot Stripper.
Maryland Steel Co. (J.W.C.)

A = hydraulic cylinder for transferring mold.
B = " " " " lifting "
C = " " " " pushing out ingot.
D = links that slip over lugs, H, H.
E = Special ingot mold.
F = ingot G = mold cars.

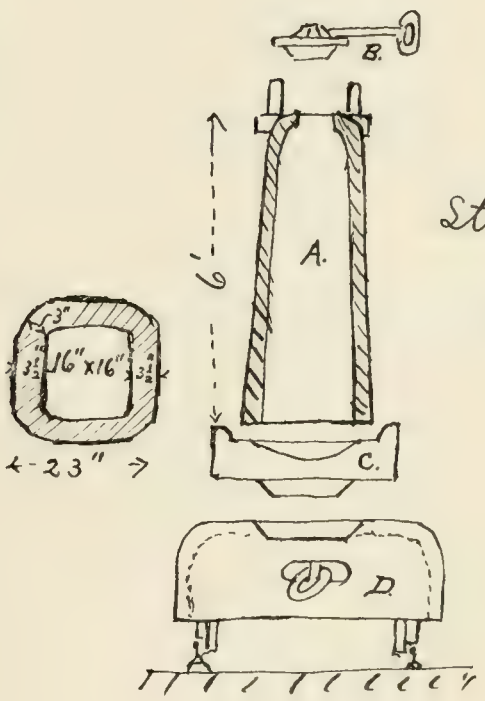


Fig. 127.
Standard Mold
and
Mold Car.
(J.W.C.)

Fig. 127

A = Standard mold, closed top.
B = cast iron mold cap.
C = stool.
D = mold car (used by Maryland Steel Co.)
E = cross section of mold.

(Text continued from page 89.)

strains of expansion and contraction when heated and cooled, and yet not brittle, as they would be if made of white iron. The ingot in cooling shrinks away from the mold. The mold is first lifted off by an ingot crane (fig. 128, 130) and then the ingot; or in the other method the mold-car, with the mold and ingot upon it, is pushed by a locomotive under the stripper (fig. 126) which pushes out the ingot leaving it on the mold car while the mold is lifted off and set onto the mold car standing on the track to the left (fig 126.)

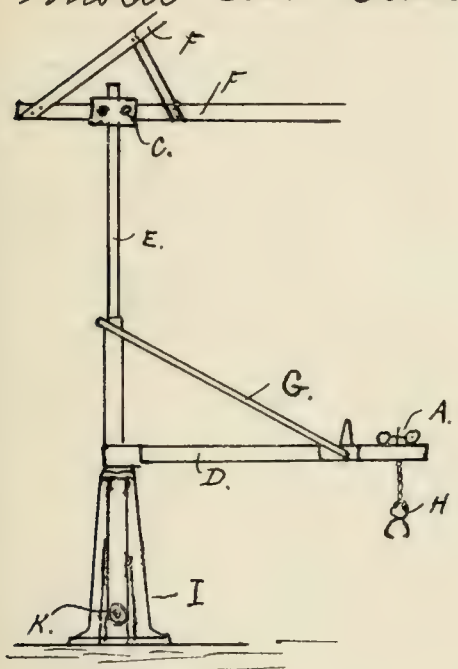


Fig. 128.
Holley Hydraulic Ingot Crane.
(Jeans, "Hist. of Steel", p. 397.)

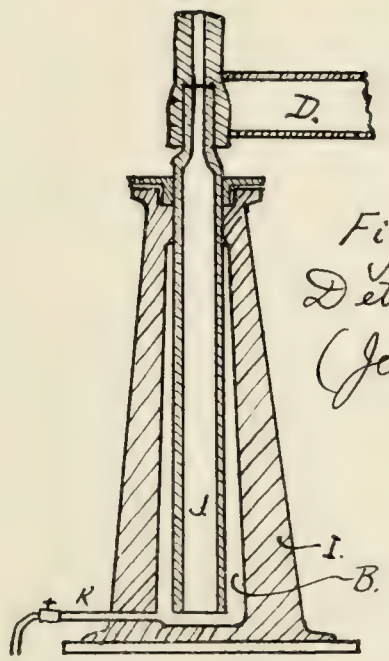


Fig. 129.
Details of fig. 128.
("Jeans, Hist. Steel" p. 397.)

Figs. 128, 129.

A = Buggie.
B = hydraulic cylinder.
C = "Top steadiment"
D = Jib.
E = Mast.
F = Roof of building.
G = Tie.
H = Ingot tongs.
I = Stand.
J = Plunger.
K = Inlet for water.

Note.
This crane is swung by hand. The jib and tie turn on the mast.

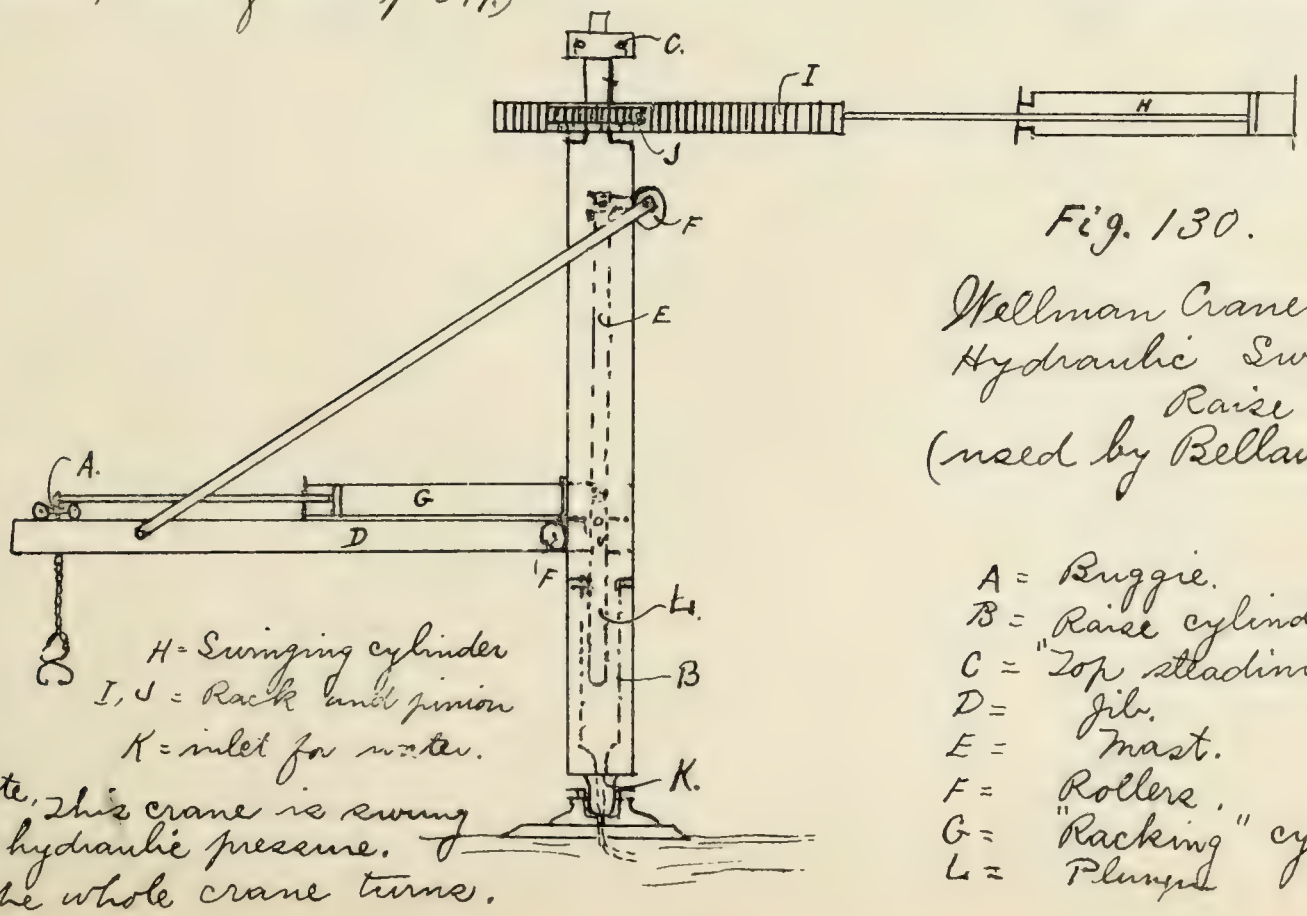


Fig. 130.
Wellman Crane with Hydraulic Swing, Rack and Raise.
(used by Bellaire Steel Works.)
(I.W.C.)

H = Swinging cylinder
I, J = Rack and pinion
K = inlet for water.

Note. This crane is swung by hydraulic pressure. The whole crane turns.

A = Buggie.
B = Raise cylinder.
C = "Top steadiment".
D = Jib.
E = Mast.
F = Rollers.
G = "Racking" cylinder.
L = Plunger.

Bessemer (con.)

Rolling the Ingots in the Mill.

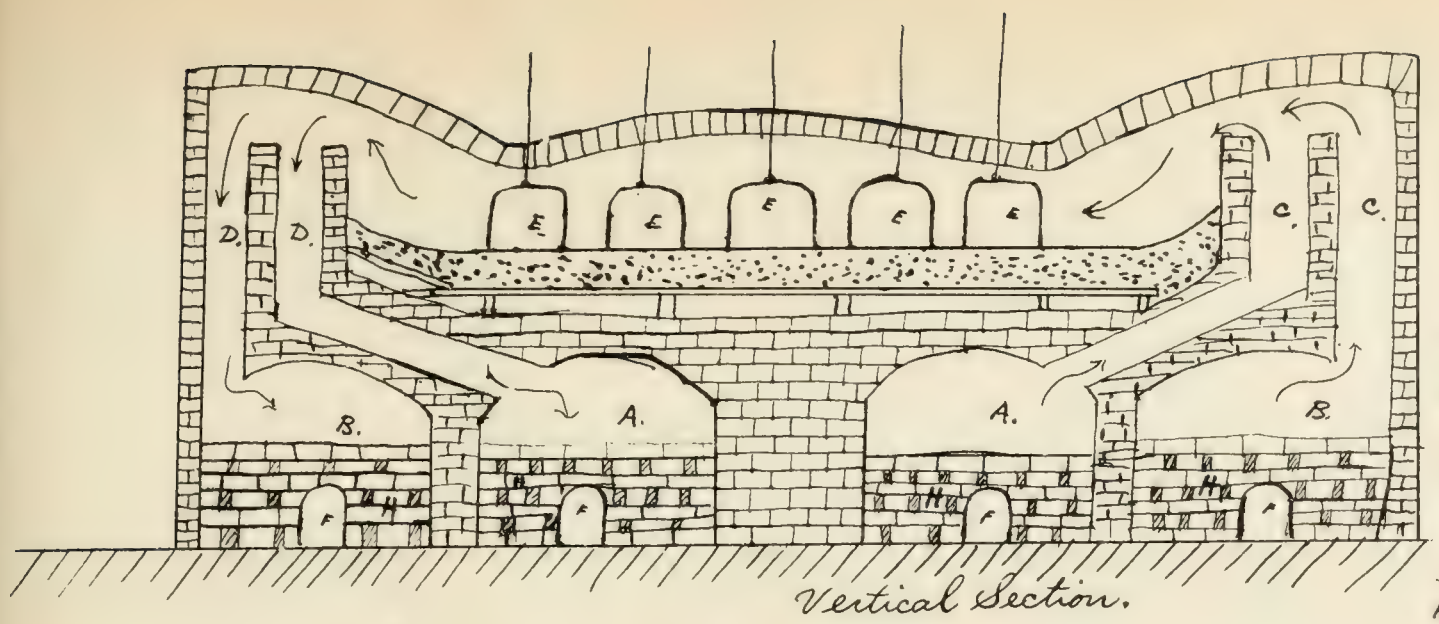
The ingot is now in the condition of a solid shell with a pasty or liquid interior. It cannot be rolled until it has become of uniform softness throughout. It is therefore charged into a soaking pit (figs. 132, 133), or else into a vertical furnace (fig. 134) where it is kept in a vertical position so that any gas bubbles may collect at the top, and is allowed to equalize (or "soak") in the current of hot gases for an hour. Then the ingot is taken from the soaking pit by an electric traveller (fig. 136) and rolled down in the blooming mill (figs. 137, 138) to a 7"x7" section "bloom", which, after having the ragged ends cut off by hydraulic or steam shears (figs. 137, 142), is finished — usually without reheating — in a rail-mill (fig. 144) into a rail or into a 4"x4" section "billet." Sometimes the bloom is allowed to partly cool and is then reheated in a reheating furnace (fig. 131, 135) before being finished. This reduces the number of defective rails, but increases the cost for fuel and labor.

The handling of the ingot, bloom, and rail is done by machinery altogether; the ingot by charging cranes (figs. 135, 136) and ingot manipulators (figs. 139, 140, 141); the blooms by power-driven feed tables (figs. 137, 138); the rails by "live rollers" and tables (fig. 144); the scrap and "cropends" fall by gravity into a little car. fig. 137).

The whole ingot is rolled out into one long rail and this is cut into standard lengths (30', 33', 45', or 60') by a single motion of the series of hot saws (fig. 145) The unequal amounts of metal in the head and flange would cause the rail, if straight when hot, to be bent when it had cooled; so the rail is curved the other way, while hot, by going through the cambering machine (fig. 146), and when cold it is nearly straight.

After cooling on beds the rails are finally straightened under presses (steam), have bolt holes drilled in the ends, are inspected, and are loaded onto cars by electric loading machines.

Rails which have defects near the ends can be used & the amount of 10% of the whole number of rails in the order, by sawing off the defective part with a cold saw (fig. 147). Cold saws without teeth, drawn at a high speed are also used, but the slow toothed saw cuts more evenly and truer to length. Bessemer steel ingots made for other purposes than for rails are bloomed to a variety of sized blooms and sheared hot to length by hydraulic shears. These are reheated and rolled to more finished sizes in finishing mills.



Vertical Section.

Fig. 131.

Siemens Heating Furnace. (J.W.C.)

A = Regenerative chambers for gas.
B = Regenerative chambers for air.
C } { Uptakes } { Vertical sections
D } { Downtakes } { sections
E = Doors.
F = Flues to stack.
H = "checkers"

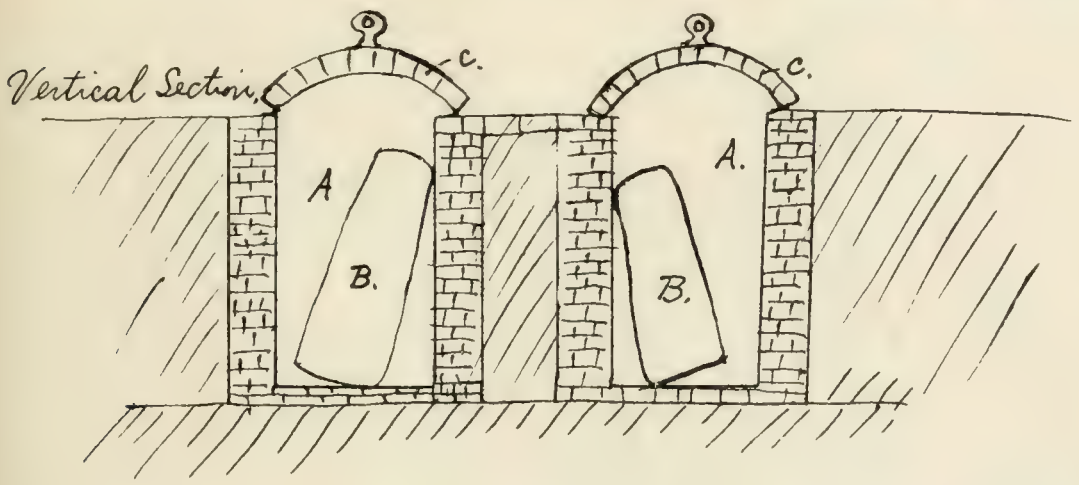


Fig. 132. (J.W.C.)

Gjers Unfired Soaking Pit.

A = Soaking pit.
B = steel ingot.
C = covers of soaking pit.

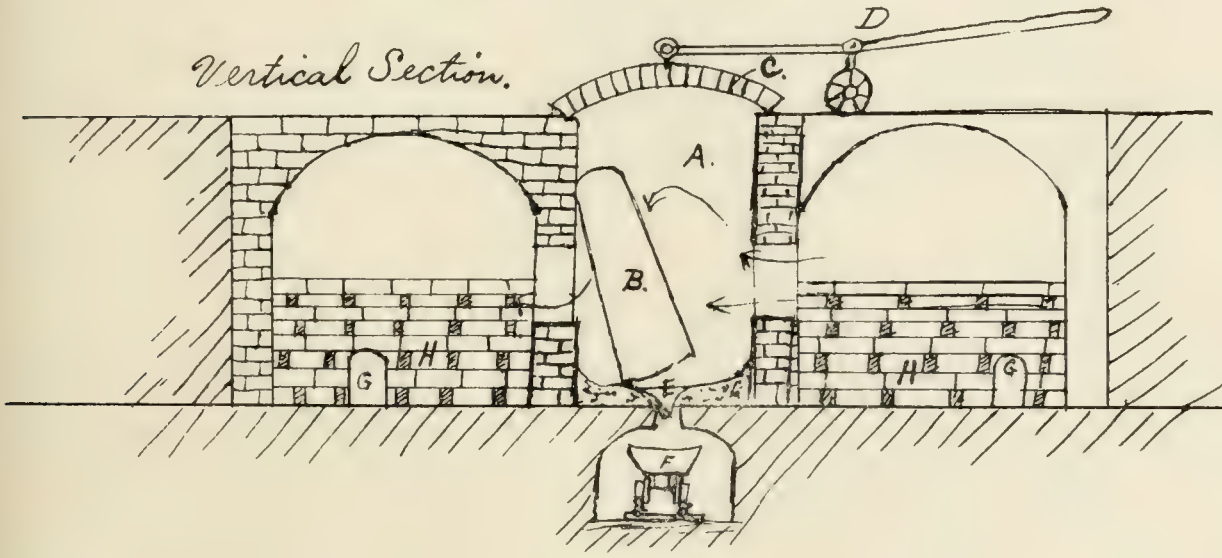


Fig. 133. (J.W.C.)

Hainsworth Regenerative Gas-fired Soaking Pit.

A = soaking pit.
B = steel ingot.
C = cover to pit.
D = lever and wheel for removing cover.
E = hole for tapping off slag.
F = car for slag and scale.
H = "Checkers."
G = flues to stack.

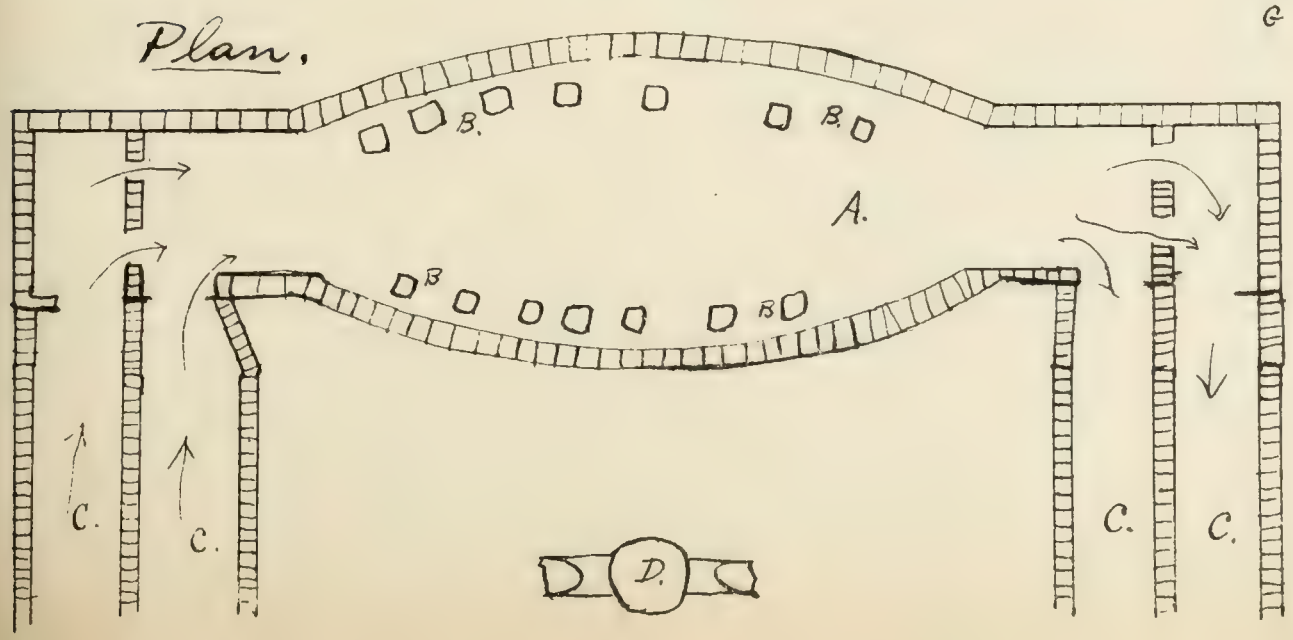


Fig. 134. (J.W.C.)

Vertical Heating Furnace Used by Maryland Steel Co.

A = Furnace.
B = Steel ingots.
C = Regenerative chambers with checkers.
D = stack.

Fig. 135.

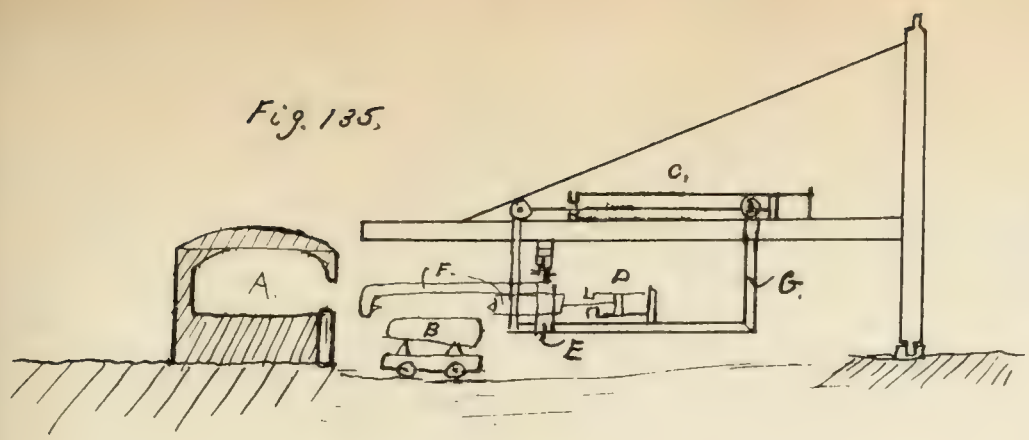


Fig. 135.
(J.W.C.)

Kennedy Hydraulic Charging Crane.

A = Reheating oven.
B = steel ingot.
C = hydraulic cylinder for frame
D = " " " clutch
E = " " to raise "
F = clutch.
G = frame.

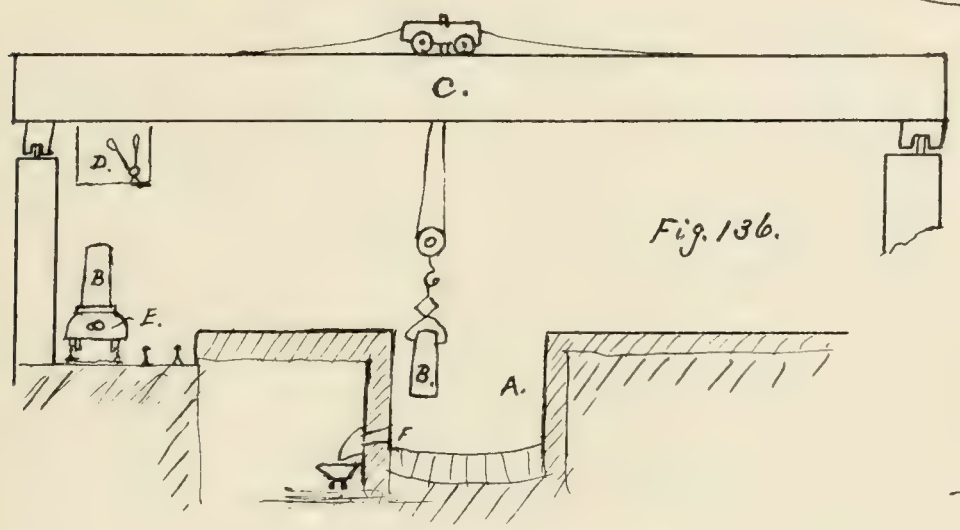


Fig. 136.

Fig. 136.
(J.W.C.)

Electric Traveller.

A = Soaking pit.
B = steel ingot.
C = electric traveller.
D = operating levers.
E = mold-car.
F = slag tap.

Fig. 137.
2-High Reversing Blooming Mill.
(J.W.C.)

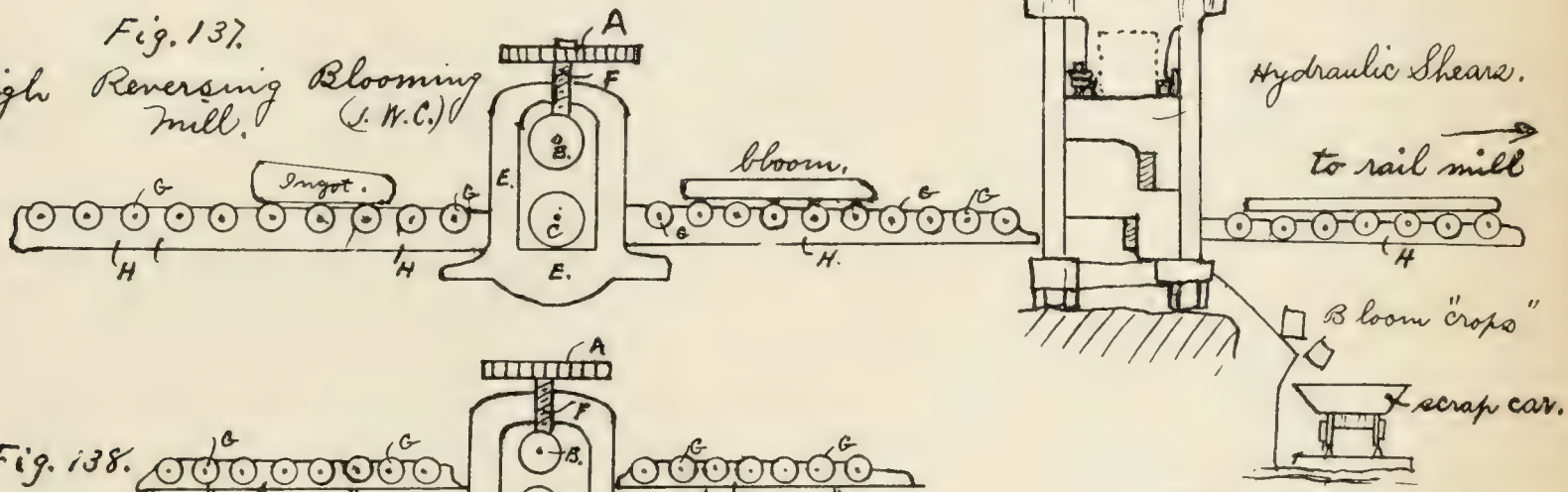
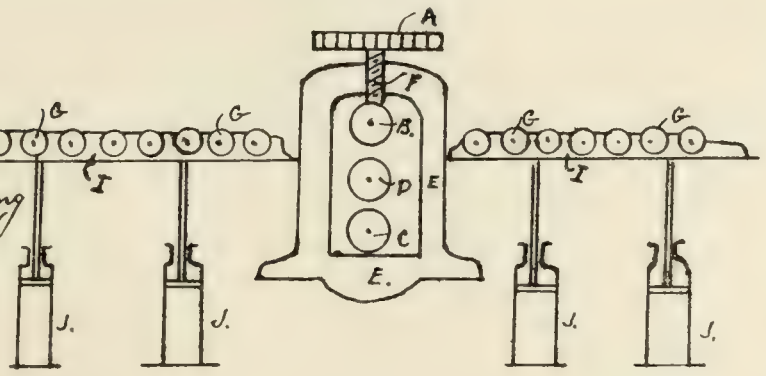


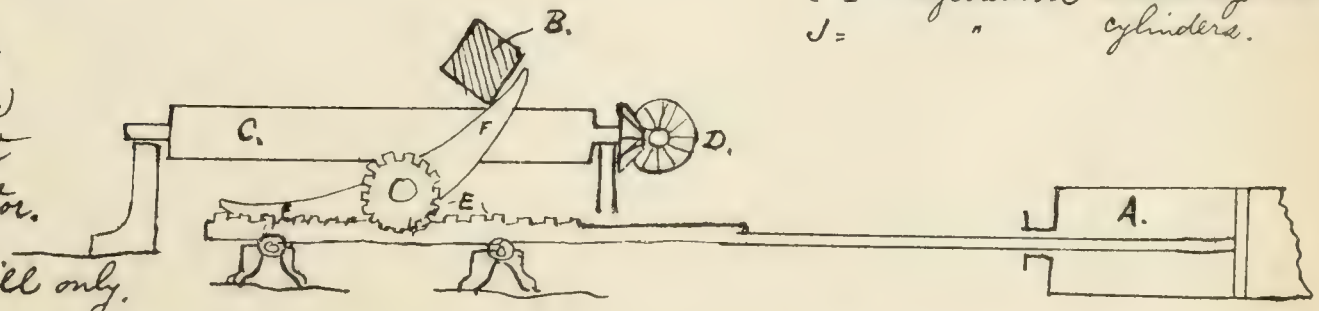
Fig. 138.
3-High Blooming Mill.
Non-reversing.
(J.W.C.)



Figs. 137 and 138.

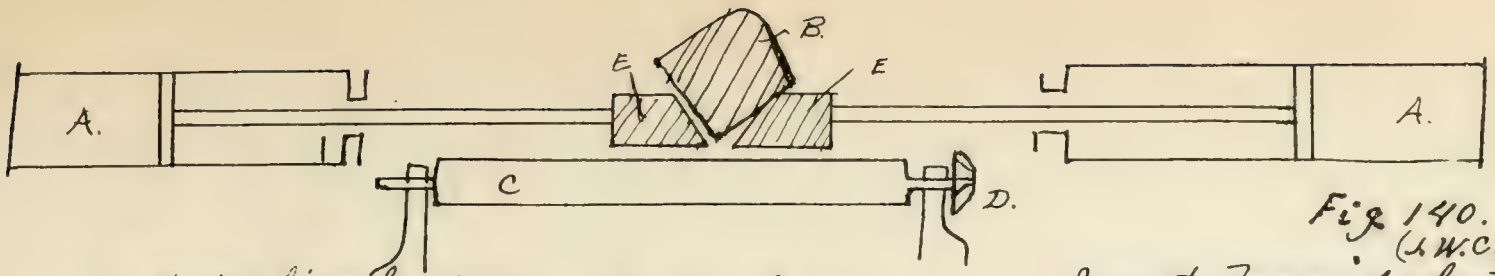
A = Master-wheel
B = Top roll.
C = Bottom "
D = Middle "
E = Housing.
F = " screw.
G = "live" rollers.
H = tables.
I = hydraulic elevating tables.
J = " cylinders.

Fig. 139.
(J.W.C.)
Mason Ingot Manipulator.
For 2-High Mill only.



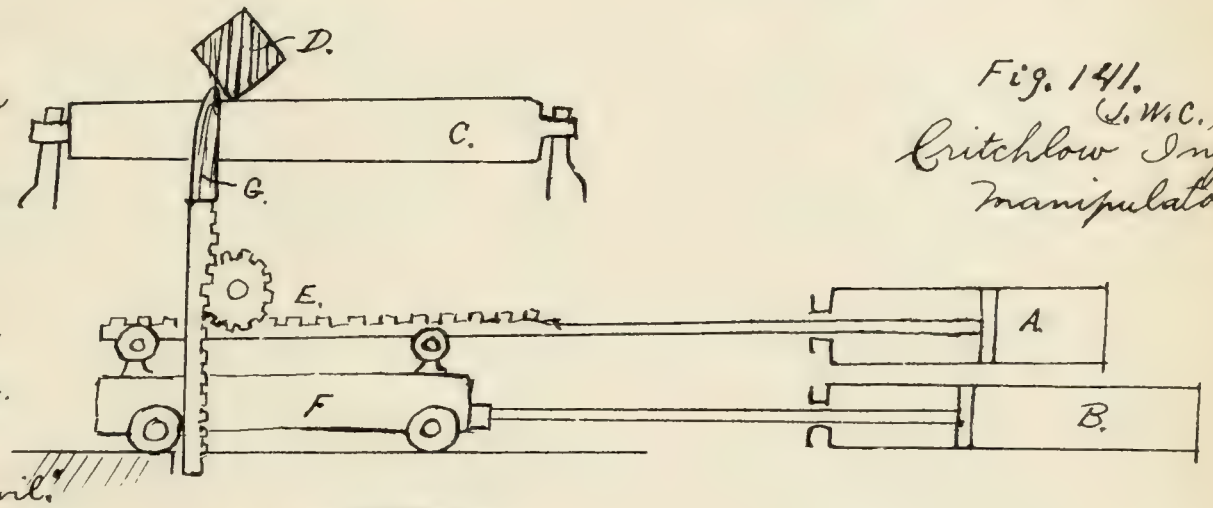
A = Hydraulic cylinder.
B = Steel ingot.
C = "live" roller.
D = bevel gear.
E = rack and pinion.
F = the arms of the "go-devil."

(Note:- The ingot manipulator is often called the "go-devil.")



A = Hydraulic cylinders.
B = steel ingot.
C = "live" roller.
D = Bevel gear.
E = head on piston rods.

Fig. 140.
(J.W.C.)
Ingot Manipulator for 2-High Mill.
(used by Cambria Iron Co.)



A = elevating cylinder (Hydraulic)
B = Traverse cylinder (hydraulic.)
C = "live" roller.
D = steel ingot.
E = rack & pinion.
F = carriage.
G = "finger" or "go-devil."

Fig. 141.
(J.W.C.)
Critchlow Ingot Manipulator.

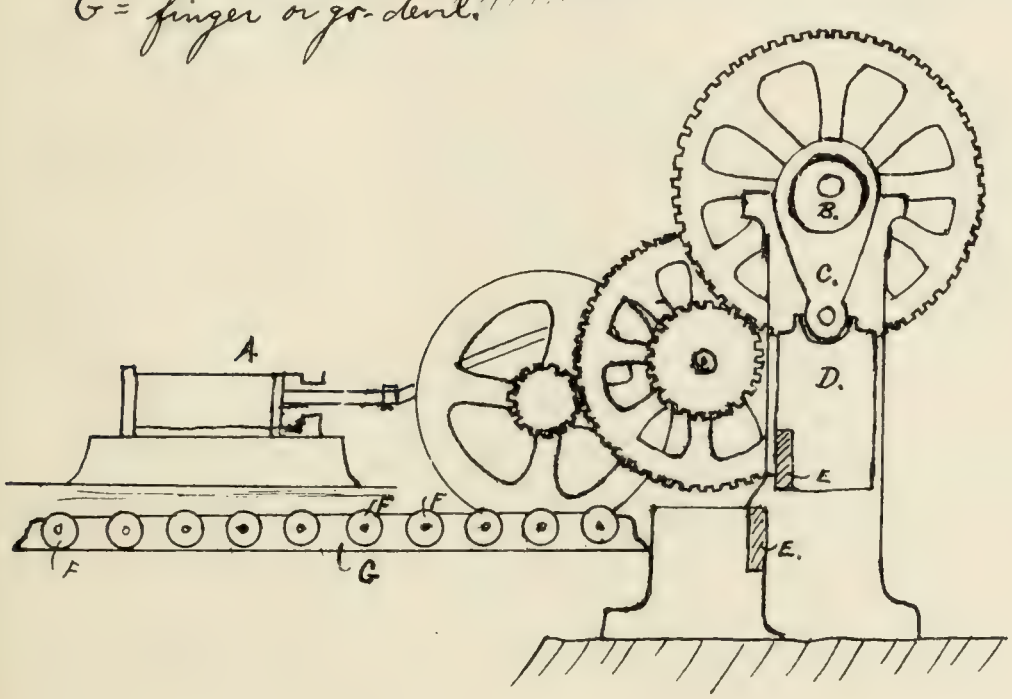


Fig. 142.
(J.W.C.)
Steam Shears.

A = steam engine.
B = eccentric
C = " strap.
D = cutting head.
E = knives.
F = "live" rollers
G = shear table.

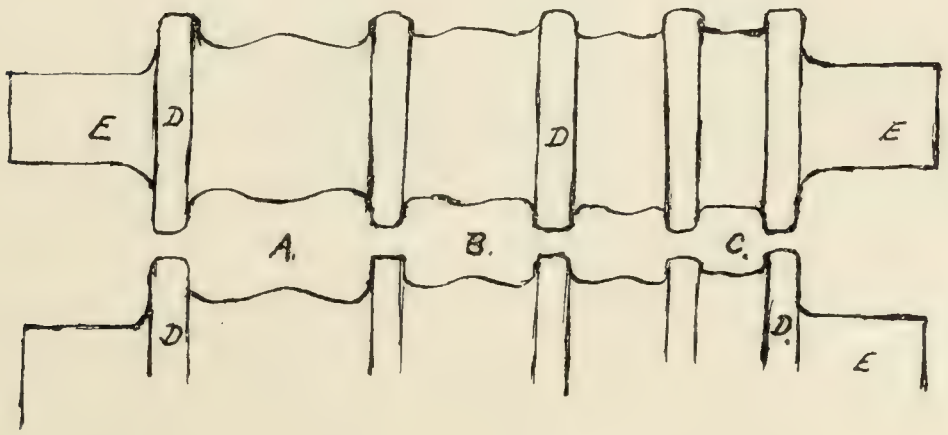


Fig. 143.
(J.W.C.)
Bloom Rolls.

A = Roughing pass.
B = Edging pass.
C = Finishing pass.
D = Collars.
E = Necks.

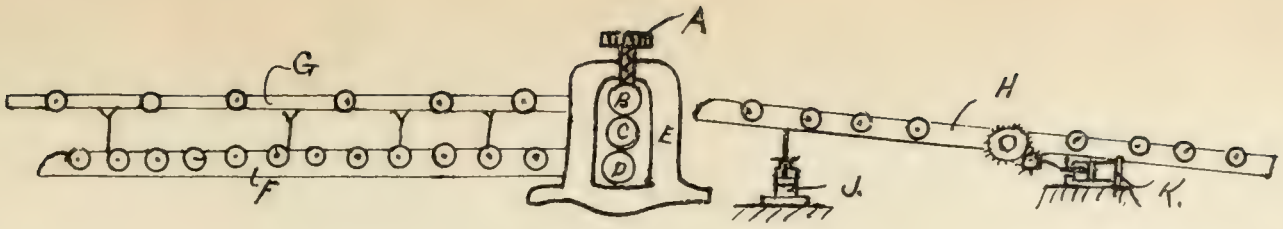
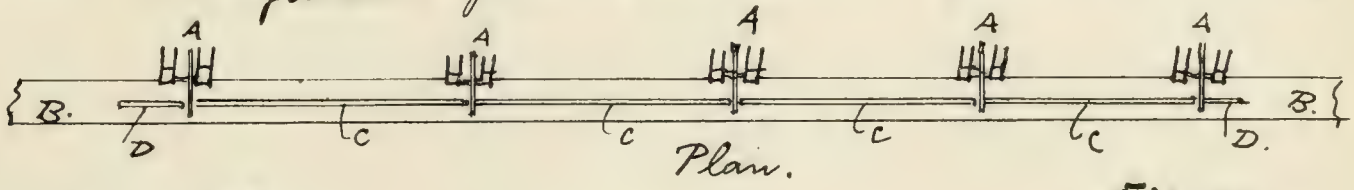


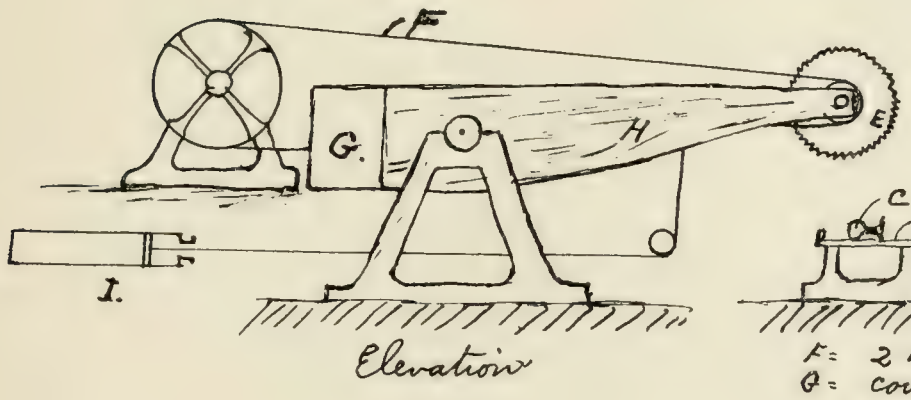
Fig. 144.
(J.W.C.)

3-High Rail Mill.

A = Master wheel.
B = Upper roll.
C = Middle "
D = Bottom "
E = Housing.
F = Table with live rollers for lower passes.
G = Table with rollers – to receive from upper passes.
H = Table with live rollers – receives from and feeds to upper and lower passes.
J = Hydraulic cylinder to raise & lower H.
K = steam engine to run live rollers.



Plan.



Elevation

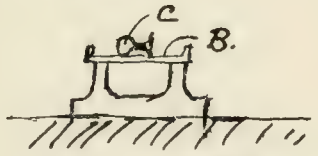
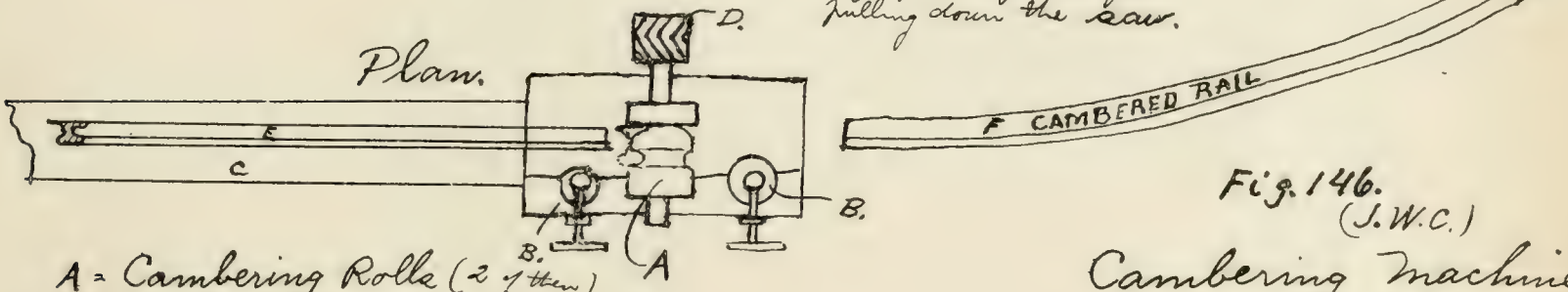


Fig. 145.
(J.W.C.)

Hot Saws.

A = Row of five saws.
B = Saw table (with live rollers.)
C = The rails cut into standard length.
D = "Rail ends"
E = The hot saw.
F = 2 Belts.
G = counter weight.
H = arm or frame.
I = hydraulic cylinder for pulling down the saw.



A = Cambering Rolls (2 of them)
B = Cambering rollers.
C = Saw table – with live rollers.
D = Gears.
E = straight, hot rail from hot saws.
F = Cambered rail.

Fig. 146.
(J.W.C.)

Cambering machine used by Maryland Steel Co.

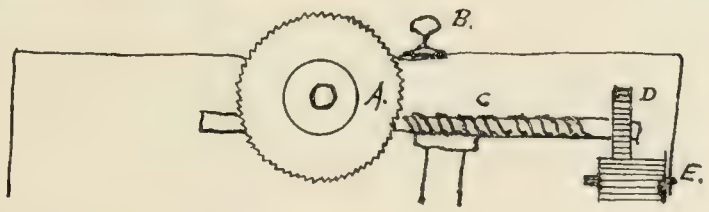


Fig. 147.
(J.W.C.)

Cold Saw.

(Cuts slowly.)

Fig. 147.

A = The cold saw.
B = " rail.
C = Worm gear.
D = Spur gear.
E = " " with very wide teeth, to allow for forward movement of

Chemistry of Bessemer Process.

The comparative rate at which the elements (C., Si., Mn.) are burned out is shown by the following diagrams which represent the American, English, German, and Swedish practice.

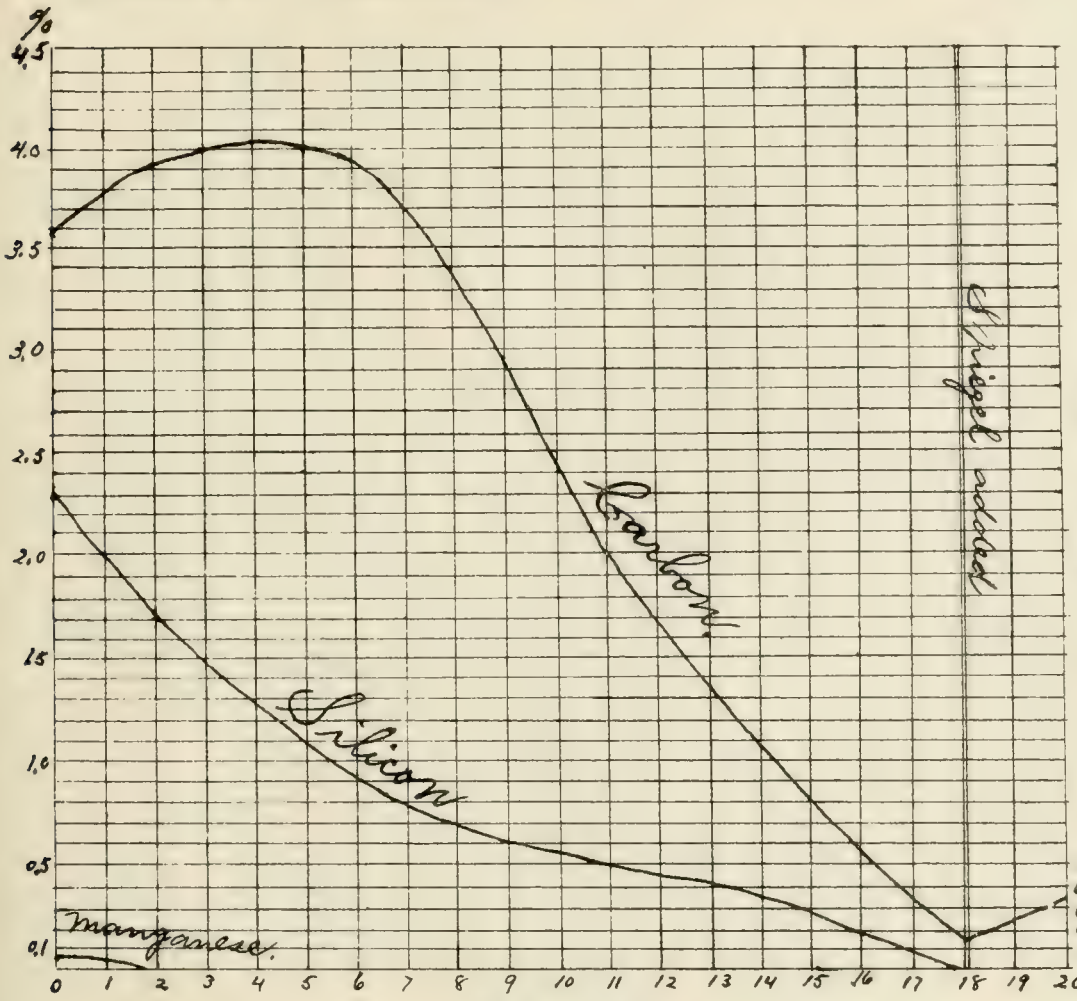


Fig. 148.

English Practice. (Sedebur, "Eisenhütten-Kunde", 1884, p. 915.)

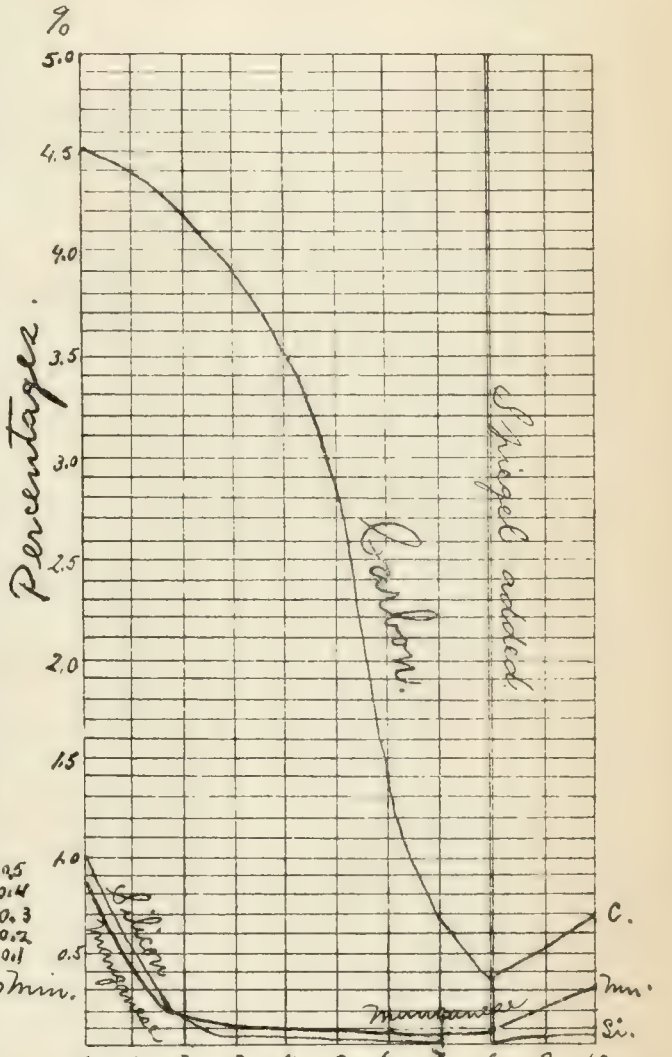


Fig. 149.

Swedish Practice.

(Sedebur, 1884, p. 918.)

In fig. 148 is shown the English method. These curves show the rate of the elimination of the elements (C, Si, Mn) from an iron rich in Si. The molten iron is not heated so very hot before charging. C. does not begin to burn till about 1.25% of the Si. is burned out.

The Swedish process (fig. 149) requires that the iron be superheated before charging; probably the iron comes direct from blast furnace.

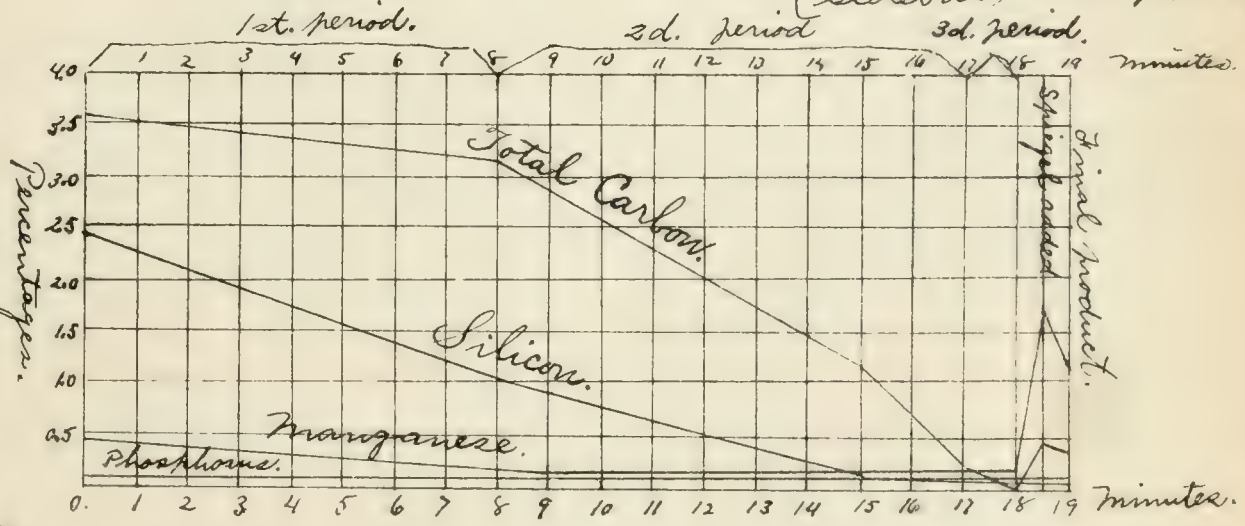


Fig. 150.

American Practice. (A. I. M. E. Vol. IX, p. 262.)

Fig. 150 shows the American practice in 1880. at present, iron with much lower Si. is generally used; but no diagram of present practice was available for these notes.

Chemistry of Bessemer Process. (con.)

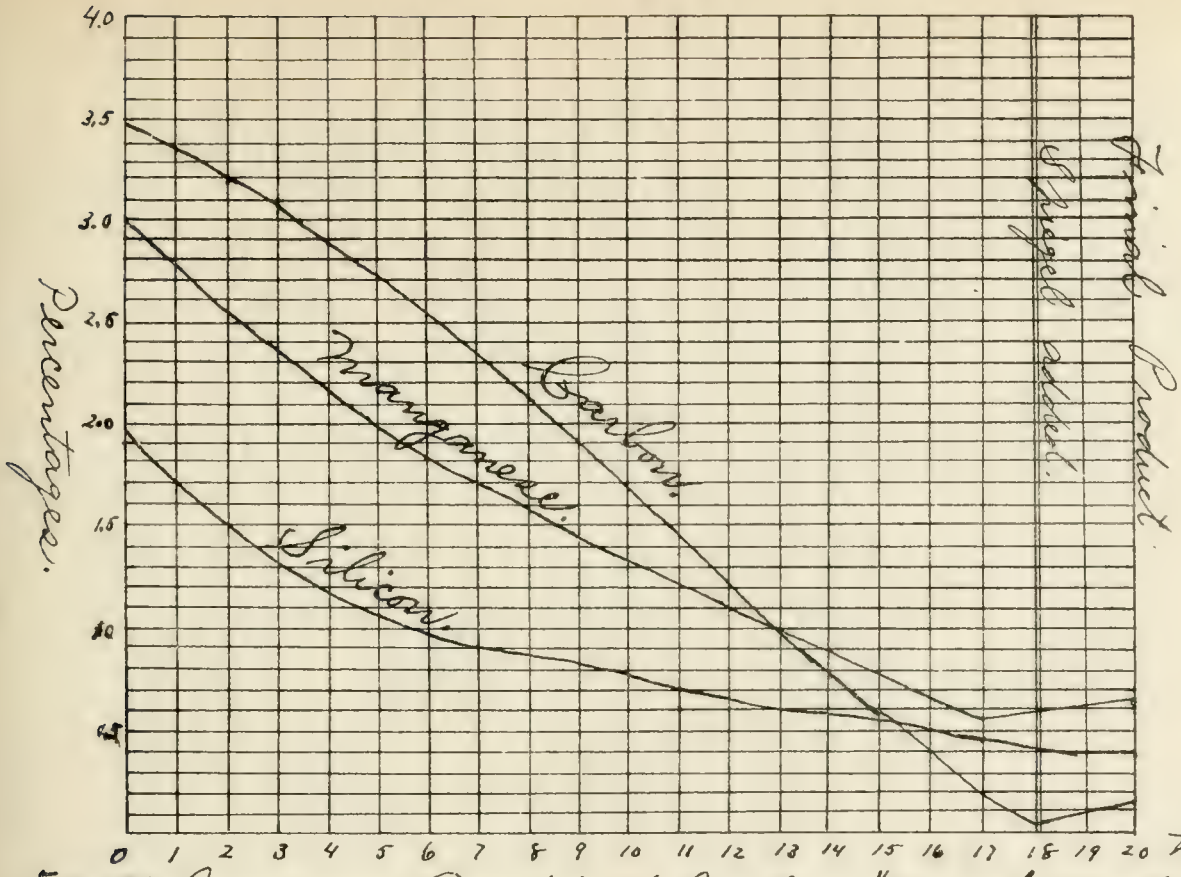


Fig. 151. German Practice. (Ledebur, "Eisenhüttenkunde", 1884, p. 917.)

"The heat available for heating the bath is that produced by the combustion of silicon, manganese, phosphorus, and carbon minus the heat absorbed in raising the products of that combustion to the temperature of the bath." (A.I.M.E., XXII, p. 390.) The following table of heat produced by combustion of elements is from same reference; the initial temperature is retained at 1400°C., but that of the products is assumed at 1600°C.

Heat Produced by Combustion of Elements.

				absorbed by O. & N. of air		Net
Si. (to SiO_2)	— 1 Kilo. produces	7830 cals.	(C°) —	1892 cal.	=	5938 cal.
C. (" CO.)	— " "	2473 "		2330 "	=	143 "
Fe. (" FeO.)	— " "	1201 "		569 "	=	632 "
Mn. (" MnO.)	— " "	1201 "		569	=	632 "
P. (" P_2O_5)	— " "	5766 "	Retained in batty	1430 Cal.	=	4336 " *

*(this figure for net heat of P burning to P_2O_5 is ..... "Basic Bessemer Process", Wedding 1891, p. 157)

In blowing high manganese iron (Mn. = 3% or over), German practice (see fig. 151), it is found that more Mn. remains at the end than if there were only 1% at the beginning; .25% Mn. sometimes remains. In such a case no ferro. is needed and the steel may be cast without recarburizing. If there is high Si. at first, much Si is also left. In a hot blow much Fe is oxidized. Only two thirds of the iron oxide can be cleared out by the Mn. (A. I. M. E. vol. IX, p. 395.) An overblown charge is also much oxidized.

Conditions of the combining of P. and Fe.

Sir Lowthian Bell gives the following results ("Jrnl. of Mfg of Iron", p. 403) from puddling iron at low heat. The FeO oxidized P. to P_2O_5 which united with more FeO forming phosphate of iron (slag). The puddled balls contained .086% P. These were subsequently heated in contact with this slag at a much higher temperature for two hours. The metallic

Chemistry of Bessemer Process (con.)

Fe. took away some P. from the slag (as phosphide of iron) and the P. increased in the puddled balls to .25% (Howe, "Met. of Steel", p. 54). Having a mixture of metallic iron, CO, $3Fe_2P_2O_5$, and SiO_2 (as in acid Bessemer process), the SiO_2 will expel the P_2O_5 (as it expels SO_3 from Na_2SO_4 in glass making) forming silicate of iron, and leaving the P_2O_5 and Fe. At the high temperature of the Bessemer blow and in presence of CO the P unites with the Fe as phosphide.

Having metallic iron, $3FeO.P_2O_5$, and CaO (as in Basic Bessemer process), the CaO partly displaces the FeO, forming phosphate of iron and lime from which the Fe cannot take the P except by the help of CO and SiO_2.

C., Si., and Mn., all oppose the removal of P. from Fe. as they have a stronger affinity for O. than P. has; (the Si. and Mn. at low temperatures and the C. at high) and therefore they tend to prevent the formation of P_2O_5, or reduce it when formed by taking away its oxygen.

Composition of Rail Steel.

Rail steel contains .40 to .60% C.; .08 to .10% P.; .75 to .90% Mn.; .05 to .10% S.; .05 to .15% Si; sometimes .10 to .20% Cu. If C. is above .60% the rail will be too brittle and will break under the "drop test" (a ton weight falling 16' (?) on a piece of rail 3 feet long resting at ends on supports) unless the P. is below .08%. If the C. is below .40% the rail is too soft to stand the wear of the car wheels, unless for light traffic. If P. is above .10% or Mn. above 1.00% the steel will be brittle ("cold short"). If Mn. is much below .75% the ingot will crack in rolling. (A. I. M. E. vol. X, p. 302). S., if above .10% shows in the rolling by short feathery cracks ("hot short") especially if rolled at a low red heat. This is corrected by higher Mn. and also by higher Si. Si. up to .15% improves the rolling qualities of the steel, but in large quantities it makes it brittle (thus a very brittle open-hearth steel had Si = .20% Mn. = 1.00% C. = .25" and P. = .12% - J.W.C.). Cu. is thought to increase "red shortness". For soft steel to make into barb wire and wire nails, and for sheets for tin plate and galvanized iron the C. is from .10% to .15%, and Mn. .30 to .50%. Most of the Bessemer steel made goes into these two kinds (rail steel, and soft steel). Some grades of intermediate carbons for axles, machinery, toe calks, etc., are also made.

The Basic Bessemer Process.

The Basic Bessemer process is used for making steel from cast iron which is too high in P. to be converted by the acid Bessemer process. The pig iron must have P = 2.5% to 3.0% in order to give enough heat; a higher percentage may be used but the waste then increases. Si. must be low (below .50%) because it makes the slag siliceous, which prevents the removal of all the P. (Bell, "Prin. of Mfg. of Iron," p. 400); it also wears out the basic lining of the converter. Less than 2.0% P. will not give heat enough and the deficiency cannot be made up with Si., Only irons of a limited composition then can be economically treated. The basic lining for the converter is made (B. I. S. '90, vol. I, p. 217) by grinding (magnesia limestone (dolomite), having MgO = 15% & 20% and low SiO_2 (below 2.0%); making it into brick in a brick machine, with water and a little basic slag from a previous heat to hold the brick together, and burning them at a high heat in kilns; these bricks are ground up to the size of peas, mixed with 10% of boiled tar, and this material is used for lining converters by ramming a layer 12" thick against the sides around central wooden formers. Converter bottoms are rammed up with the same material, but ordinary clay tuyeres are used ("pin bottoms" are also used.).

The phosphoric iron is usually remelted in cupolas, where it has a strong tendency to absorb S. Hard burned lime (low in SiO_2) having been charged into the converter to the amount of 12% of the pig charge, the iron is poured in upon it and the blow is carried on as in the acid process until the "drop" of the flame. The P. is then about half out, and then the blowing is continued for 4 or 5 minutes (the "afterblow") and the rest of the P. is burned out. The end of the operation is determined by the number of cubic feet of air blown during the "afterblow", and this is known by counting the number of revolutions of the blowing engine.

The bath is now nearly chemically pure iron. It is recarburized and the steel cast as in the acid process, except that the slag is run off from the top of the casting ladle into a car, because P may go back to the metal from the slag if this is allowed to mix with it in the presence of Si or CO since these take O. from the P_2O_5 or phosphate of lime, and P. unites again with Fe.

When the slag is cool it is ground very fine and used as a fertilizer as it contains 18 to 20% of phosphoric acid and 40% of lime.

Basic Bessemer (con.)

The basic process has not been used much in this country, mainly because phosphoric pig iron of the proper composition cannot be made much cheaper than iron which will do for the acid Bessemer.

In Austria basic pig iron is melted in reverberatories (instead of cupolas). The melted iron is nearly free from Si., and does not absorb S. as in cupolas. But the cost of this would be too great in this country.

In working with the basic process, P. can be reduced to as low a point as wanted even to .005%. But for rail steel and Bessemer soft steel such very low P. is not necessary, and when it is wanted low, as for boiler plate, it is generally made in the open hearth furnace.

The "duplex" process for converting iron which is high in both Si. and P. (as is the case with most irons made in the South) consists in first blowing it in an acid lined converter to eliminate the Si. and part of the C., and then transferring to a basic lined open hearth furnace or to a basic converter to take out the P. This process has been tried and promises well.

Some Analyses of Basic Bessemer Materials.

Dolomite limestone - $CaCO_3 = 49\%$; $MgCO_3 = 43\%$; $SiO_2 = .50\%$; $Fe_2O_3 = .40\%$; $Al_2O_3 = 3.5\%$

Basic Pig Iron - P = 2.75% ; Si. = .25% ; Mn. = 2.0%
S. = .03% (after remelting S = .15%.)
(This is a white iron very low in Si. and it absorbs much S. in the cupola.)
At drop of flame P = 1.50%

at end of 4 minutes "afterblow" - P = .04 % ; S = .04%
Mn. = .15% Si = .009%

after recarburization — P = .052%; Mn. = .52% ; S = .008
Si. = 005%

In the steel — C = .08% ; Si = .006%; S = .01%
P = .048% ; Mn = .36%

Converter Slags (Basic Bessemer)

Locality.	CaO	P_2O_5	MgO	MnO	Fe_2O	SiO_2
Hoesch.	37.8%	17.0%	3.2%	3.3%	19.7%	6.2%
Peine.	35.0	21.5	3.0	2.3	19.0	6.5
Pottstown, Pa.	42.0	19.0	—	5.0	21.0	3.0

Puddling
Bessemer
Open-hearth

"Slags" and Remedies.

The difficulty of too "cold" iron (low Si.) is overcome by side blowing (see fig. 119). If the iron has become partly chilled in the converter by a long delay, coal or coke may be thrown in during the blow. Also ferromanganese or spiegel can be added, the burning of the Mn. serving to raise the temperature.

If the iron is too hot steel scrap is added, or pig iron may be used if low in Si. Also steam may be admitted to the blast pipe. Very high S. in the iron is partly cured by increasing the Mn. in the steel to the upper limit, and also by keeping the ingot an extra long time in the heating furnace.

In blowing very low Sulphur iron for soft steel there is danger of hollow ingots. If S. is not below .04% this is less liable to happen.

If a charge is overblown, more pig iron can be mixed with it and the blast turned on again until the flame drops a second time. Si. and Mn. help to cure overblown metal.

Ingots charged too soon into the heating furnace will not roll well from being too soft inside.

"Burnt steel", i.e., heated so hot as to cause a recrystallization, must be cooled down and gradually brought up to softness again.

Converter linings may give trouble in either of two ways; (1.) they may build up on the sides forming "kidneys"; (2.) or they may "cut out" and become too thin in spots.

"Kidneys" form in case the converter slag is thick from being too siliceous; also when the intervals between operations are long thus cooling down the converter too much. Linings "cut out" when the slag is too thin and has much lime or manganese in it; also when the blows are too hot. Much lime will rapidly flux any lining; just enough helps to flux the SiO_2 in the slag and keep it thin; Al_2O_3 added to the blow also helps and does not attack the lining so readily.

Cost of Production of 1 Ton (2240 lbs.) of Bessemer Steel Ingots.

Locality.	No. of converters	Materials: Pig	Scrap.	Ferro.	Total.	Val. of scrap.	Net.	Labor.	Officials & clerks.	Fuel.	Supplies Repairs.	Taxes.	Total.	year.
U. S.	2.	$18.161	—	$.621	$18.788	$.018	$18.770	$1.716	$.051	$.535	$.616	$.006	$21.694	1889.
Europe.	2.	$14.747	—	(this cost included in pig)	$14.747	.098	$14649	.686	.070	.531	1.086	.011	17.033	1888-89
Grt. Brit.	2.	$12.659	.688	.353 .112 *	13.812	.206	13.606	.649	.185	.238	.541	.019	15.238	1889.

* cost of spiegel. These figures are from "Sixth Annual Rep. of Com. of Labor," 1891, p. 156

The Open Hearth Process.

The Open Hearth process for making steel consists in melting down the charge upon the hearth of a Siemens regenerative furnace. The process divides itself into three divisions according to the character of the charge:—

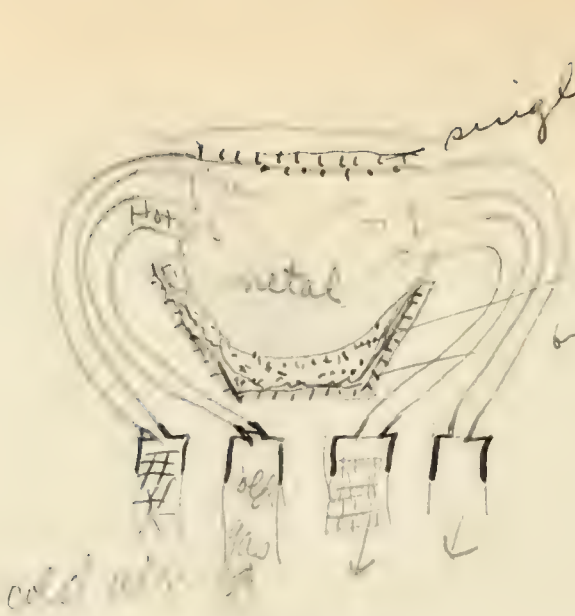
1. Martin Process — using pig iron and scrap only.
2. Siemens Process, or "pig and ore" process — using pig iron and ore only.
3. Combination Process — using pig iron, scrap, and iron ore.

The combination process is that generally used in this country. In it the pig and scrap are first melted, yielding a molten metal with too high percentage of carbon; the iron ore is then added to reduce the percentage of carbon.

The process was made possible by the invention of the regenerative furnace which can produce a temperature high enough to keep the bath fluid when in the condition of wrought iron. As in the Bessemer process, so here there are two main divisions — the Acid and the Basic Open Hearth Process, having respectively siliceous and lime-magnesia linings, and like the Bessemer only low phosphorus stock can be used with the acid lining, while with the basic lining high phosphorus stock is used. The open hearth can make steel of any grade of carbon (including all made by Bessemer process) while in the Bessemer only medium and low carbon steels (below .60% C.) are made. (An exception is the Swedish practice where, having low P. and low Si. pig made in charcoal blast furnaces, all kinds are made, and the blow is interrupted at any desired carbon.)

The open hearth process is generally confined to making spring steel for car and wagon springs (C = .80% to 1.00%), structural steel for roofs and bridges, steel for agricultural implements, for boiler plates (C. = .15%, P. = .03%) and for steel castings.

As the melting stock used is largely the "crop ends" and scrap from the Bessemer process, the two processes can be advantageously carried on at the same works.



Reversible, to heat air.

Products.

Springs .8-1.0 C

Structures

Agri. Tools C .15 P .03

Boiler plates

The Open-Hearth Furnace.

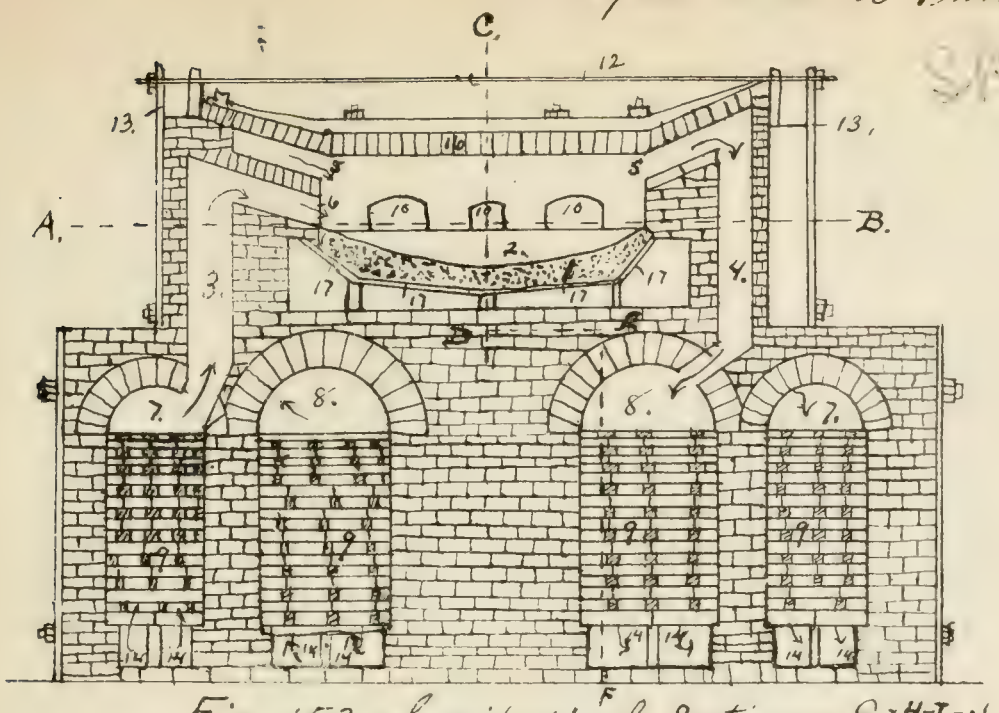


Fig. 152. Longitudinal Section on G-H-I-J.

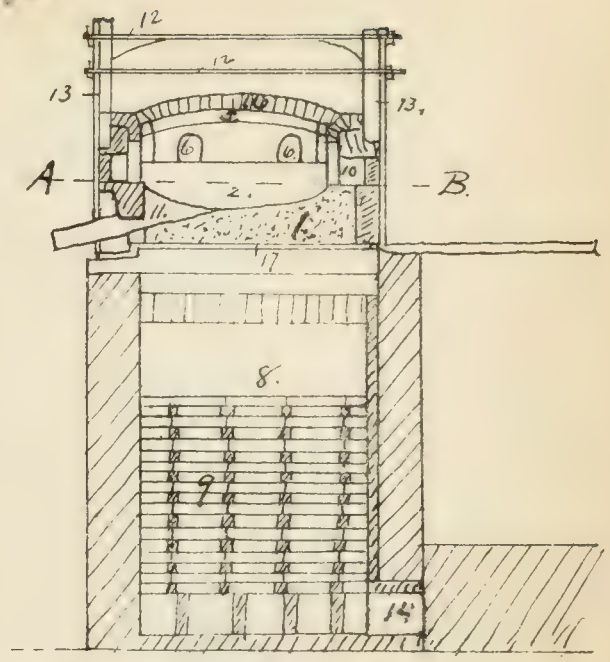


Fig. 153. Cross Section on C-D-E-F.

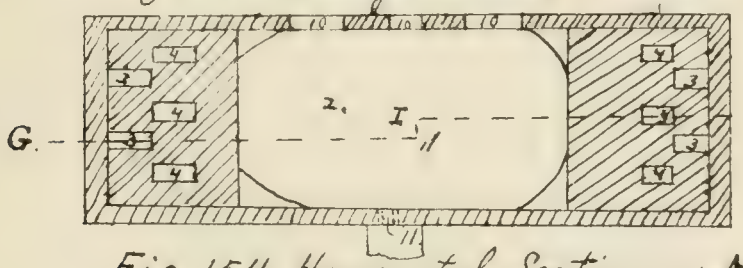


Fig. 154. Horizontal Section on A-B.

The Open Hearth Furnace.
(Figs. 152, and 153 are from A. I. M. E. vol. XXII, p. 358)

1. = Bottom.
2. = Hearth.
3. = Flues from gas chamber to hearth.
4. = " " air " " "
5. = air ports.
6. = Gas ports.
7. = Regenerative gas-chambers.
8. = " air- " .
9. = Checker-work.
10. = Charging doors.
11. = Tap hole.
12. = Tie rods.
13. = Binders.
14. = Flues to reversing valves.
15. = Reversing valves (butterfly.)
16. = Roof.
17. = Bottom plates.
18. = Flue to stack.
19. = Flue to admit cold air.
20. = " " " " gas.

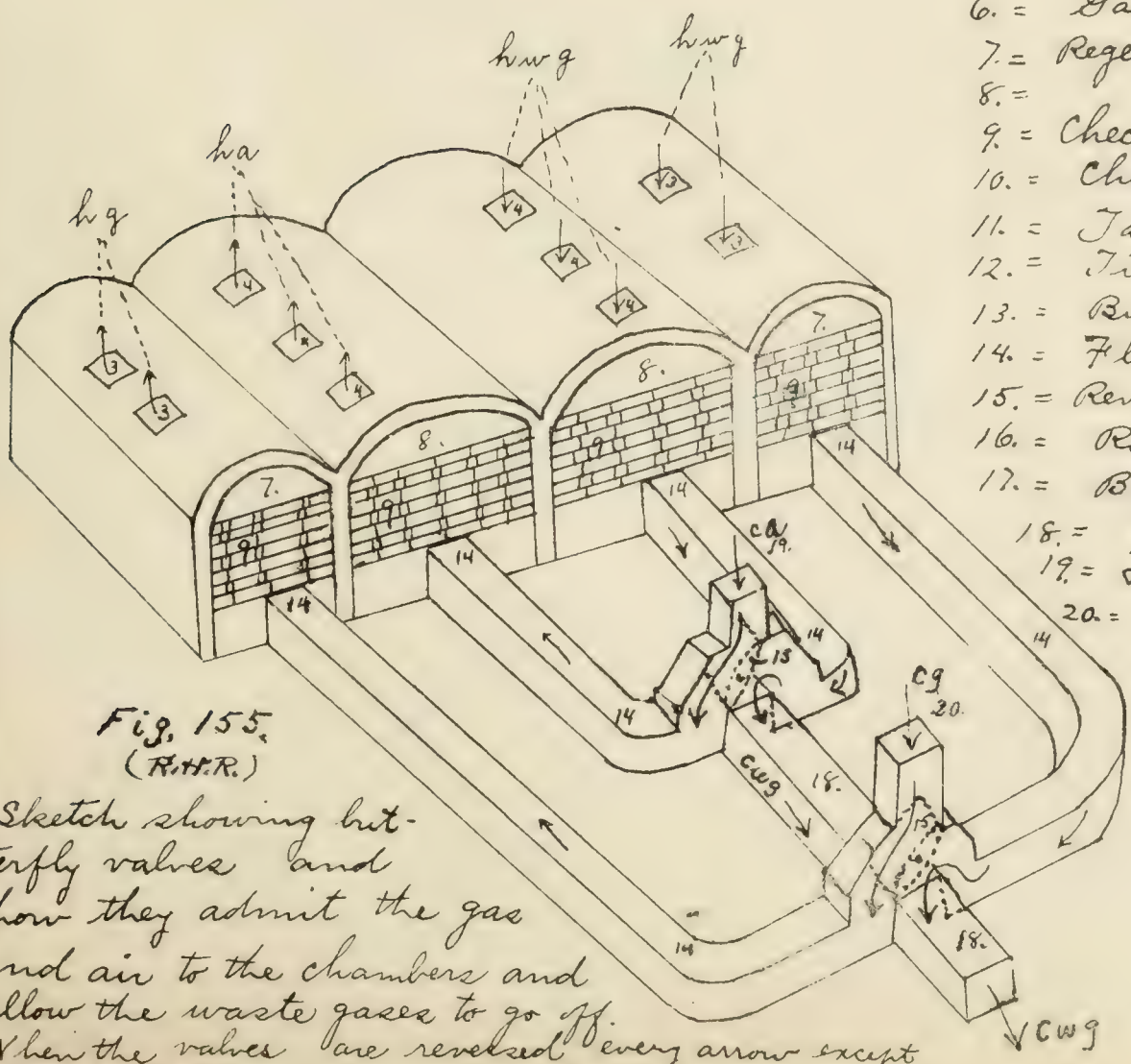


Fig. 155. (R.H.R.)

Sketch showing butterfly valves and how they admit the gas and air to the chambers and allow the waste gases to go off. When the valves are reversed every arrow except at Ca 19, Cwg, Cg 20 is reversed.

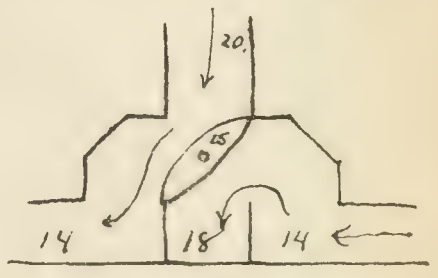


Fig. 156. (R.H.R.)
Butterfly Valve.

Lash Open-Hearth Furnace.

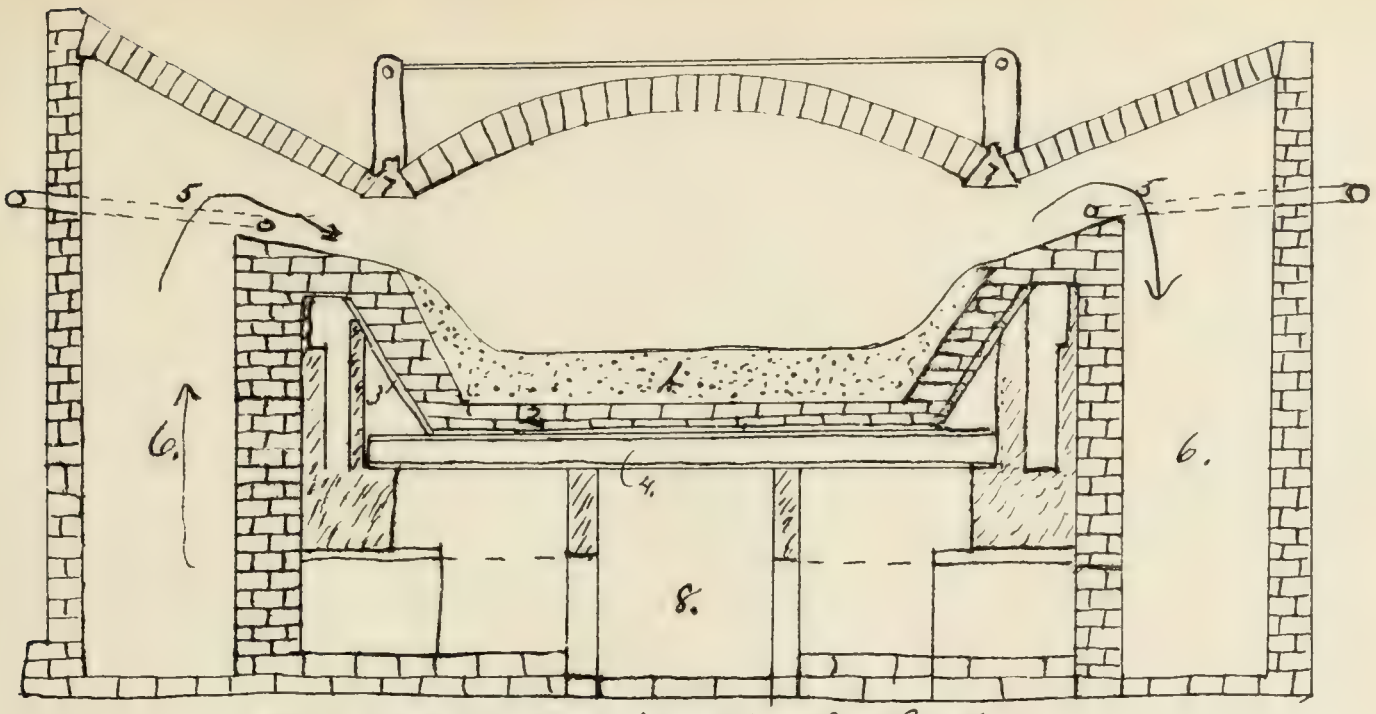


Fig. 157. Longitudinal Section.

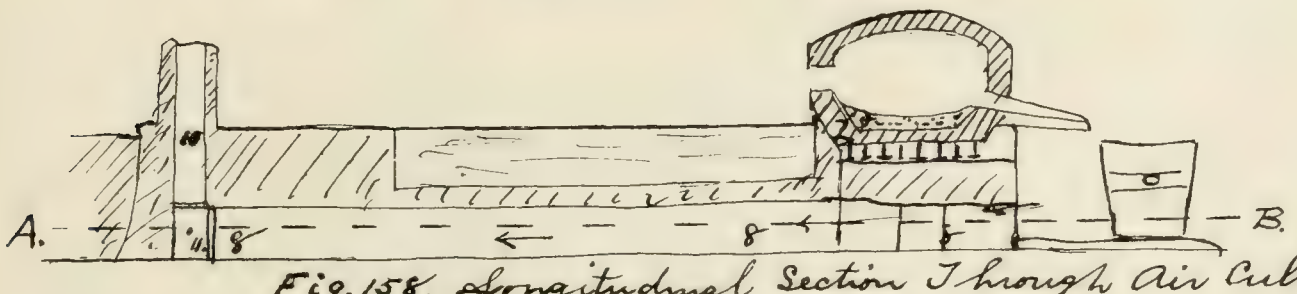


Fig. 158. Longitudinal Section Through Air Culvert.

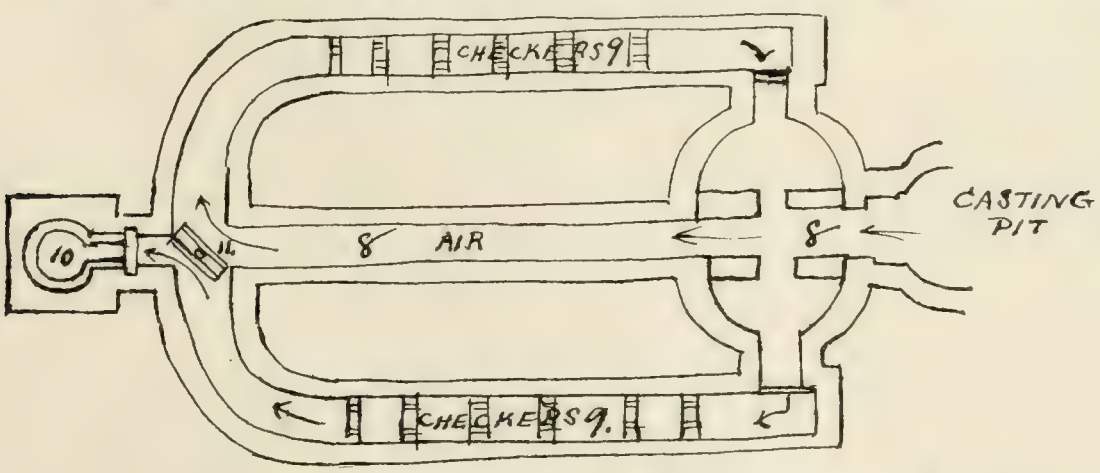


Fig. 159. Horizontal Section on A-B.

Lash Open-Hearth Furnace.

(Figs. 157,-8-9 from. Journ. I. & S. I. 1890, ep. vol. p. 278, 280; also. A. I. M. E. vol. XVI, p. 698.)

1. = Bottom.
2. = Lining.
3. = Bottom plates - or shell.
4. = Beam supporting bottom.
5. = Pipes for natural gas.
6. = Flues from regenerative chambers & hearth.
7. = Water cooled keystone plate (iron)
8. = air culvert.
9. = Horizontal regenerative chambers.
10 = Stack. 11. = Butterfly valve.

The Open-Hearth Plant.

The plant consists of open-hearth furnaces, gas-producers, casting pit; cranes, charging machinery, and rolling mill.

Parts of plant.

Gas producers

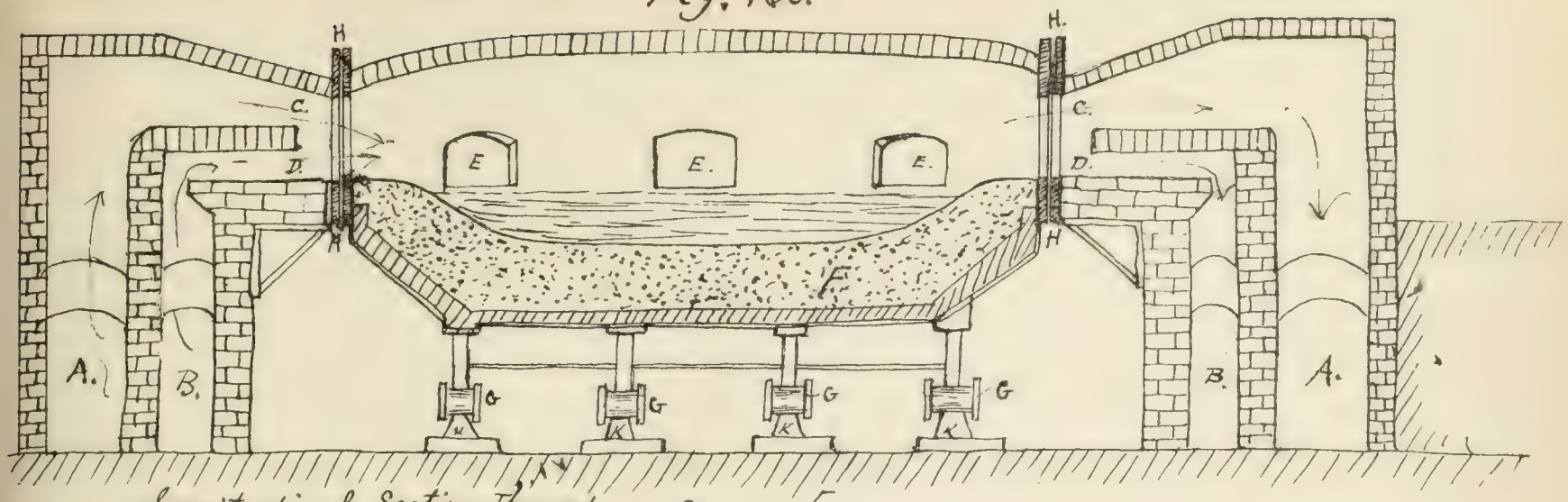
Furnace & charging machine

Casting pit & Cranes

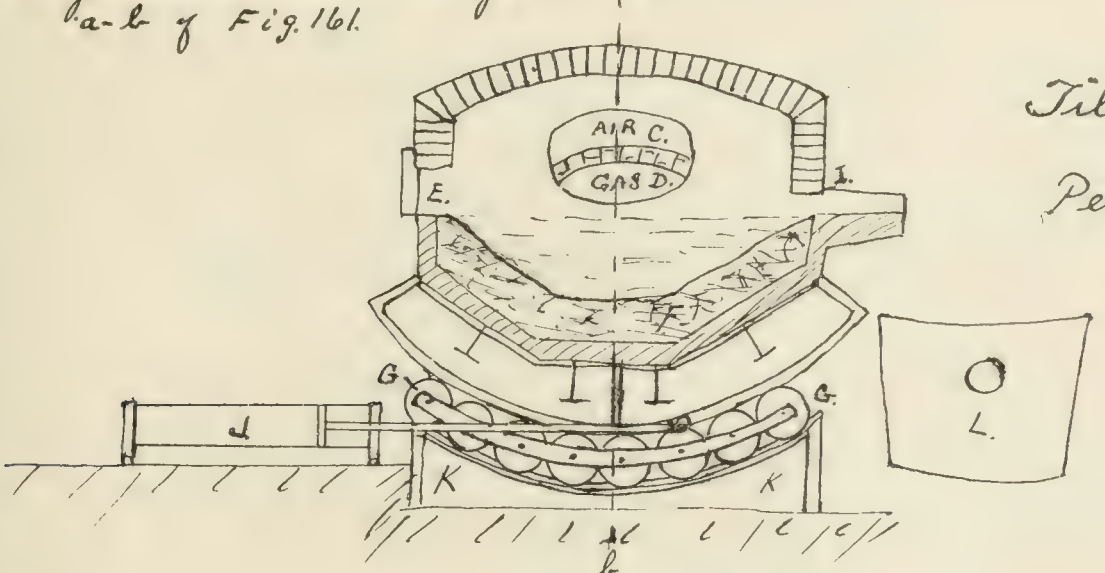
Rolling mill.

7# 50'T treated in one operation.

Fig. 160.



Longitudinal Section through a-b of Fig. 161.



Cross Section.
Fig. 161.

Figs. 160, 161.

Tilting Open-Hearth Furnace of Penn. Steel Co., Steelton, Pa. (A. I. M. E. vol. XXII, p. 360)

A = Air flues.
B = Gas flues.
C = Air ports
D = Gas "
E = Charging doors.
F = Hearth.
G = Roller-Bearings.
H = Water-cooled joints cast iron.
I = Tapping hole.
J = Hydraulic cylinder for tilting furnace.

The Furnace.
(Acid Lining)

The regenerative furnace (figs. 132, 157, 160.) used for the open-hearth process is so constructed that no solid fuel comes in contact with the metal on the hearth. The furnace proper should measure at least 15' in the clear between the ports; in large furnaces a length of 40' is not excessive. (A. I. M. E. vol. XXII, p. 351). The capacity of a furnace varies from 7 tons for a small one to 50 tons for a large furnace; 20 tons is an ordinary capacity.

The roof, sides, and ends are built up with very refractory silica brick (Dinas brick - SiO_2 = 94%; CaO = 3.20%; Fe_2O_3 = 1.00%; Al_2O_3 = 1.20%).

The Bottom or hearth is made with sand spread ~~with cold~~ spread in successive layers over a brick pave-

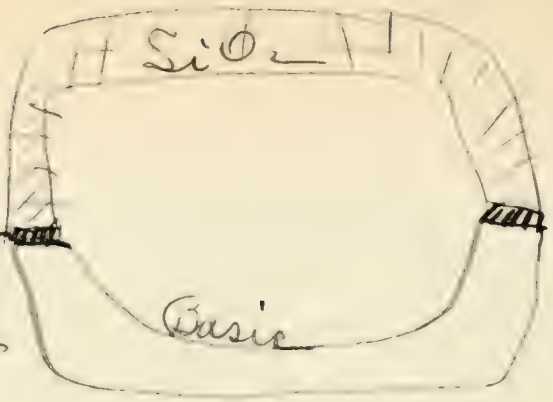
ment and sintered on by the heat of the flame. It is hollowed out to form a pool with the lowest point at the tap-hole. The sand has just enough Al_2O_3 to make it harden by heat; if it were pure SiO_2 it would be too refractory to set. A mixture of pure sand with sand less so, the mixture having SiO_2 = 97.% and Al_2O_3 = 1.8%, is used (A. I. M. E. vol. XXII, 397.)

The tap-hole is closed with a thin layer of fusible sand on the inside and infusible sand outside.

The ports (fig. 152) are built into the ends through solid blocks of silica brick.

Routine.

In starting, the furnace is heated up with a wood fire and then the gas turned on and lighted. The furnace having been brought up to a steel melting temperature, and the hearth sintered on, the charge is put in either by hand or by a hydraulic or an electric charging machine (A. I. M. E., vol. XIX, p. 313). It consists of $\frac{1}{3}$ pig iron, and the balance steel or wrought iron scrap. Half the pig iron is charged first on the bottom. (If steel or wrought iron were charged first under the pig it would be slow in melting.) The scrap then follows and the rest of the pig is put on top. The air and gas currents are reversed at regular intervals, each time coming up hotter. In four hours it is all melted, but is too high in carbon and is not yet hot enough for casting. Iron ore is added in small amounts at intervals The reaction with the C. ($Fe_2O_3 + 3C = 3CO + 2Fe$) produces CO which boils off; this is continued until the desired C. is reached. Unlike the Bessemer process, the decarburizing can be interrupted at any point. This is determined by samples dipped out at intervals during the boil. These are cooled and broken, and from the appearance of the fracture the percentage of carbon is judged; there is time enough also for an approximate chemical analysis. The boiling down occupies 3 to 4 hours. When ready chemically the bath should also be hot enough to cast. As Mn. and Si. have both gone into the slag some Mn. must be added to the bath before casting. This is done with spiegel for low carbon steels, or ferromanganese is thrown into the casting ladle while tapping the furnace, after breaking it into pieces the size of peas and heating them red hot. If steel castings are being made, Si. must also be added to prevent blow-holes (Howe, "Met. of Steel", p. 41.) This is done by charging ferro-silicon (Si = 9.5% ; Mn = 18%;



neutral layer of Chromite

$CaO.V_2O_5$ holds its P.

Basic crude materials
Big high in P
low in Si ~~O2~~ (not to slag hearth)

Scrap high in P

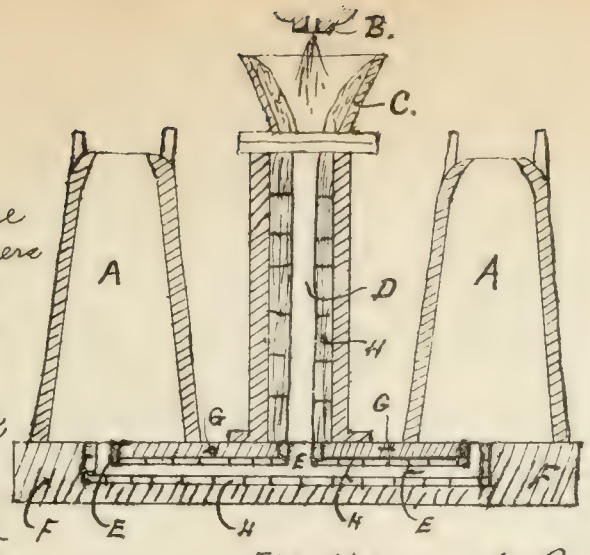


Fig. 162. H = Brick lining.

Fig 162. (J.W.C.)
Bottom - Casting — Open-Hearth Ingots for Boiler Plate.

A = Ingot mold.
B = Nozzle of casting ladle.
C = Funnel.
D = Central sprue — lined with brick or with loam.
E = Bottom runners — brick lined.
F = Bottom plate - cast iron.
G = Moveable cast iron plates.

Note:- The central sprue and bottom runners are carefully dried before the steel is poured in at C. The bottom-plate, F, is circular and is large enough for 8 molds arranged in a circle.

C = 2.0%) into the bath before tapping. Enough is put in to give about .25% Si. in the casting allowing for a wastage of half the Si. added by the ferro-silicon.

To tap the furnace a bar is driven through the tap-hole and the whole contents flow out into the casting ladle (similar to the Bessemer casting ladle) and the steel is cast in molds just as in the Bessemer process. "Bottom casting" (see fig. 162.) is often used for casting open-hearth steel. For plate steel where the ingot must be free from defects, bottom-casting is of advantage because there is no spattering on the sides of the ingot mold.

It is now customary (with Pennsylvania Steel Co. and the Homestead Works) to make very large ingots which are reduced in a slabbing mill and then cut into slabs of exact weight. The slabs, after being inspected and having the defects chipped out, are rolled in the plate mill into boiler plate and other plates. If a slabbing mill is not in use flat ingots are cast, by bottom-casting, as near to weight as possible and these are rolled "direct."

The furnace hearth is worn away along the slag line, and this is levelled up with "bottom sand" and set with the flame, after which it is ready for another operation. Repairing the bottom requires half an hour to an hour.

The Basic Open-Hearth Process.

The roof of a basic lined open-hearth furnace is built of silica brick the same as the acid, and the sides and ends above the slag line may also be the same. Sometimes the roof is carried independently, and the sides are rammed up with

tar dolomite, and the joint between the acid and basic materials made good with chrome iron ore which is passive to both. The best material for the ends and the parts is magnesia brick, which however have a tendency to crack off, and are also very expansive (a. I. m. E. vol. XXII, p. 423). The hearth is lined either with dolomite or with magnesite. The dolomite is hard burned lime made from a magnesia limestone; magnesite is made from $MgCO_3$ calcined at a high heat several times. It shrinks with each calcining. It costs more than dolomite, but is extremely refractory.

The dolomite or magnesite mixed with 10% of boiled tar is rammed with hot rammers in 2" layers all over the bottom and against the sides above the slag line. The hearth is shaped as with a sand bottom. Instead of tar as a binding material, ground basic slag may be used (about 5%) and the layers sintered in.

Upon this hearth the phosphoric pig and scrap is melted down. Before charging limestone is spread over the bottom (5% of the weight of the charge) and 5% more is mixed through the charge. This is to take up any SiO_2 and prevent it from fluxing the lime lining, and to insure a basic slag from the beginning. When the charge is melted there is too much P. as well as C. Both these elements are oxidized by the iron ore added. The escaping gas (CO) causes the agitation or "boiling" of the phosphoric bath and the metal is thus brought in contact with the basic slag and the phosphorus is removed. Lime is also added at intervals if the slag is not basic enough. When the C. is reduced to .15% the P. is usually all out except .01 or .02%. If not, pig iron is added to raise the percent. of carbon ("pigging back") and the bath again "boiled down", and this is repeated until all the P. is out. The appearance of the fracture of the sample indicates the amount of P. present. If much, it shows in the centre two crossed lines of brilliant crystals called the "phosphorus cross." It is also brittle. Quick approximate chemical determinations of P. can be made (by measuring the yellow precipitate of phospho-molybdate in a graduated tube.

The recarburization and casting is the same as in the acid process. Phosphorus may again unite with the metal, from the slag, by the action of the CO generated when spiegel or ferro- is added, and also by the Si. This is prevented by recarburizing in the ladle before the slag begins to run out, and by keeping slag out of the ladle as much as possible. A recent method of recarburization is the Darby Process (a. I. m. E. vol. XIX, 790). Ground

coke or charcoal is sifted into the stream of metal as it flows into the ladle. The carbon is absorbed by the metal and the per cent. in the steel is increased to any desired amount.

About 50% of the S. goes out during the boil. The Saniter process (Jour. I. & S. I. 1894, I, p. 553) claims to remove the S. by adding $CaCl_2$ during the boil. When using the tilting furnace (fig. 160.) the whole contents of the furnace may be poured out into the ladle, and the metal tapped back again into the furnace from under the slag and a new fully basic slag made in the furnace which will be more energetic in removing S.

The wear of a basic lining is greater than an acid especially if Si. or SiO_2 are not kept very low. After a heat any holes in the hearth are leveled with the tar dolomite, or with hard burned lime in small pieces, either mixed with tar or not, and set with the heat of the flames. The ineide of the tap hole is rammed up with tar-dolomite or magnesite, and the outside with sand.

Dolomite and magnesite can be used in contact with silica brick at points like the sides of the furnace where the temperature is not so high as at the ports. In direct contact with the flame, magnesia brick and silica brick if built together will flux each other.

The Furnace.

The original type of Siemens melting furnace (open-hearth furnace) is similar to the Siemens heating furnace (fig. 131) The ports are built so as to throw the gas and air currents down away from the roof which would be melted if exposed to the point of the flame. (fig. 152). The later forms are modifications of this. In the Pernot furnace (fig. 95-97) the revolving bottom raises the lower portions of the bath up into the flame at each revolution, facilitates chemical reactions by the motion, and also facilitates repairs. The Lach furnace (fig. 157) has its melting chamber separated from the other parts, but it is stationary and horizonal. Instead of deep regenerative chambers (like those in fig. 152) it has long horizontal passages comparatively shallow (fig. 159). This brings the whole furnace down to the level of the floor. Natural gas is used for fuel and only two regenerative chambers are needed (and these for the air), because natural gas is so

strong a fuel that it does not need to pass through the checkers, and also because in passing through them carbon from the hydrocarbons would separate out.

Vertical checkers are better because the ascending gases tend to follow up the hottest sections so equalizing the the action of the whole chamber. In a horizontal chamber the gases travel along the roof.

The tilting furnace (fig. 160) has a melting chamber carried independently of the ends which contain the ports. It rests upon rollers which roll upon tracks shaped to the segments of circles. A hydraulic cylinder rotates it about its long axis far enough to allow the pouring of the entire contents of the furnace out of the tap hole. The tap hole always remains open or loosely stopped as it is above the level of the bath except when pouring. The ports are built in metal frames which can be removed quickly when burned out, and new complete ports substituted. A water-cooled joint separates the ports from the melting chamber

The Batho furnace (Journ. I. & S. I. 1890. II, 782) has the checkers in separate riveted jackets and the air and gas currents are also carried in separate brick lined riveted pipes. This prevents leakage through the joints of the brickwork.

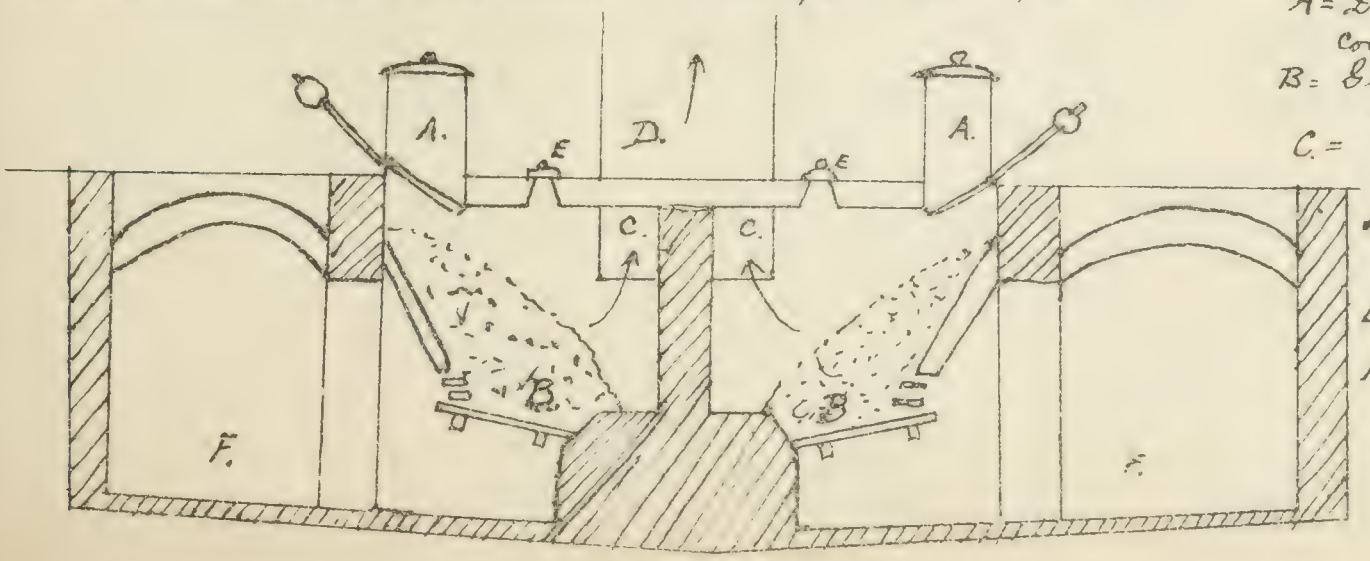
Furnaces may be of any size from 5 tons to 50. The distance between ports should not be less than 15 to 18 feet to allow good combustion. The Lash 15 ton furnace is 18' long and 15' wide.

Reversing Valves.

The oldest form of reversing valve is the "butterfly valve" (fig. 164) If the butterfly becomes warped by the heat of the

Fig. 163.

Siemens Gas Producer. (Phillips "Met." p. 99.)



A = Doubled gated coal feeder.
B = Grate charged with coal.
C. = Gas flues.
D = Gas conductor.
E = Peep holes.
F = Way for removing ashes.

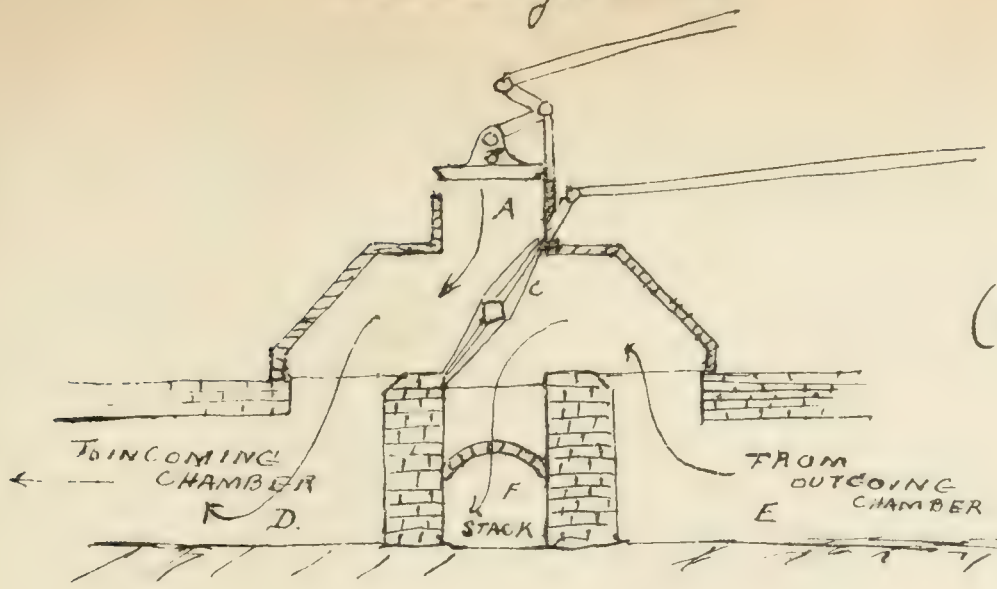


Fig. 164.

Butterfly Valve.
(Percy's, "Met. Fuel," plate 2.)

A = Inlet for gas (or air.)
B = Regulating valve.
C = Butterfly valve.
D = flue to "incoming" checkers.
E = " "from "outgoing" "
F = " to stack.

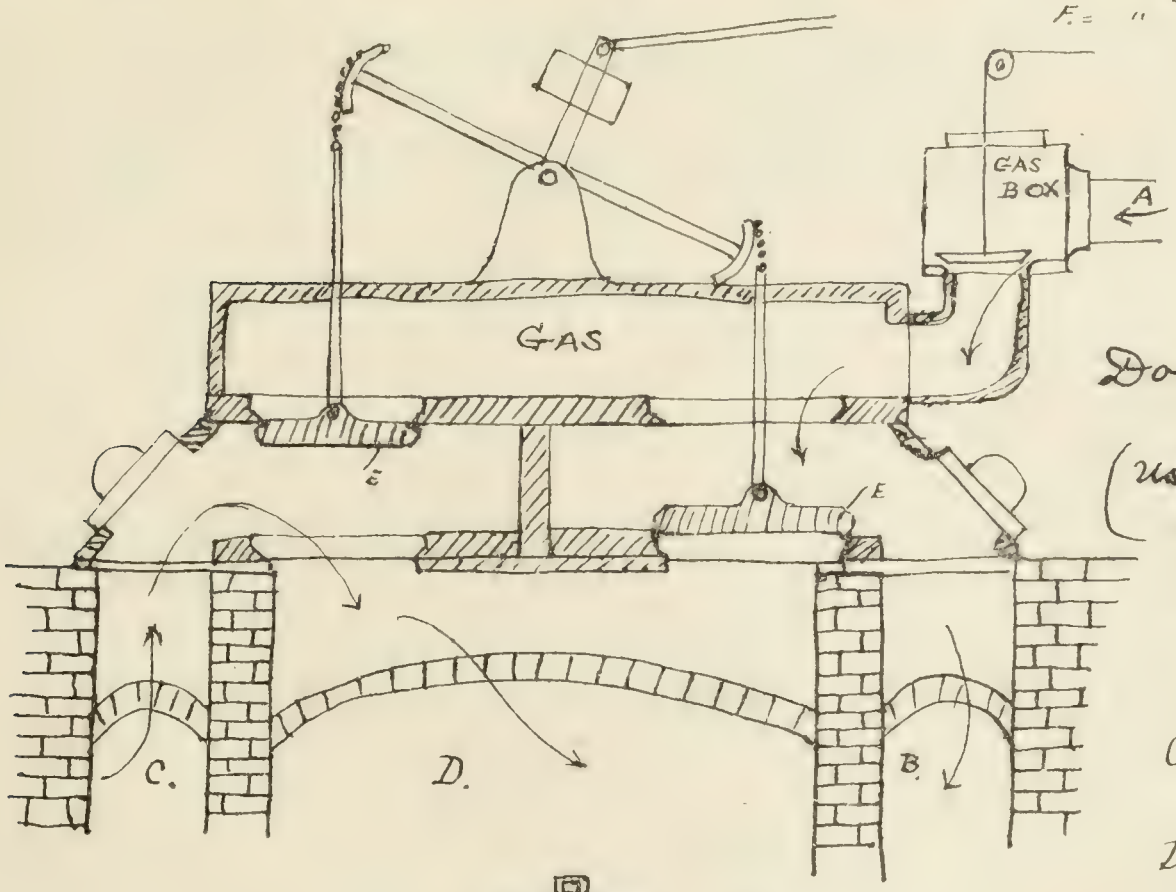


Fig. 165.
(J.W.C.)

Double Beat Valve.
(Used at Bethlehem and Pottstown.)

A = Inlet for gas.
B = Flue to checkers (cold gas going in)
C = Flue from checkers. (waste gas coming out)
D = Flue to stack.
E = The double beat valves.

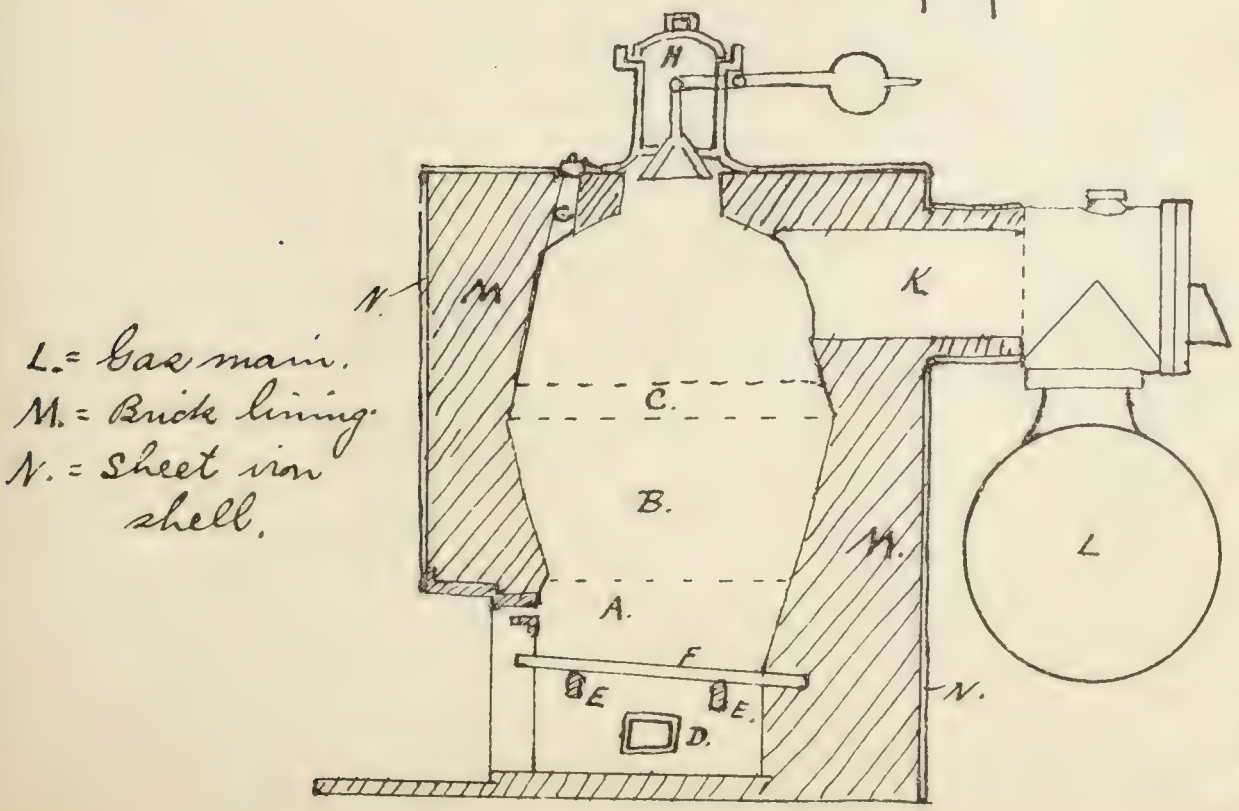


Fig. 166.

Wellman Gas Producer.
(a.I.M.E. XXII, 372.)

L. = Gas main.
M. = Brick lining.
N. = Sheet iron shell.

A. = Ash zone.
B = Combustion zone.
C. = Distillation zone.
D. = Steam-blower.
E. = Bearing bars.
F. = Grate bar.
G. = Stoking hole.
H. = Hopper.
K. = Neck to gas main.

Puddling - Weld Fe at heat below melting.
Krupp Washing - White cast Fe. at molten heat. } a
Bessemer - Steel at molten heat
Open hearth " " " " } b

$3FeOP_2O_5 + Fe = 4Fe + P \cdot FeO \cdot Fe_2O_3$

a below temp. of reaction and b at this temp.
∴ basic lining in b for P removal.

gases it is useless. This improvement by a current water-coil in the casting. is cured in the Higgs in- of water running through a The double beat valve is shown in figure 165. The seats of the double beat valve can also be water cooled.

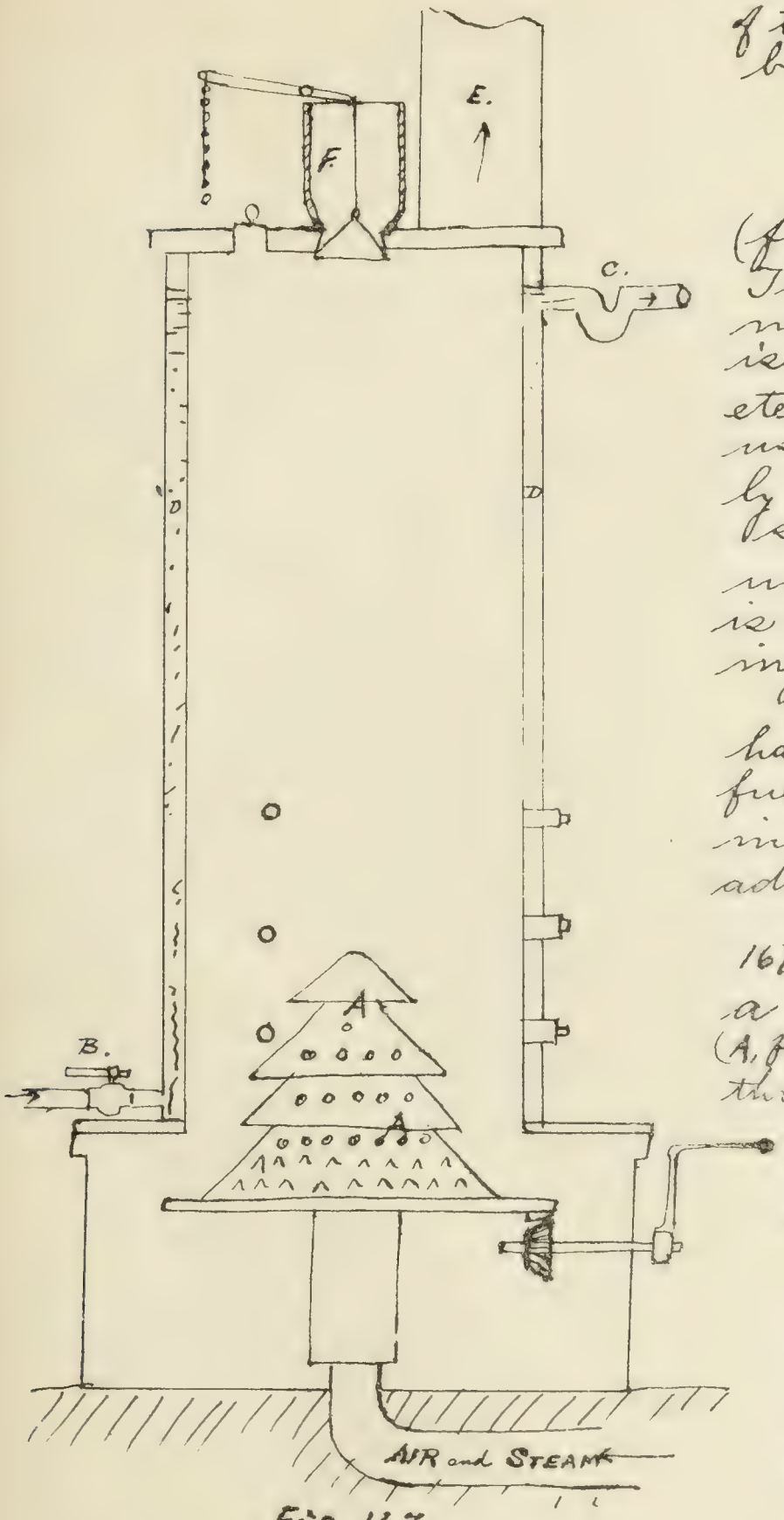


Fig. 167.

Taylor Water-cooled Gas Producer.
(a. I. M. E. vol. XV, p. 822.)

A = Revolving dome. E. = Conductor for gas.
B = Inlet for water. F = Feeding hopper.
C = Outlet " "
D = Water cooled jacket.

Gas Producers.

The Siemens gas producer (fig. 163.) is now seldom used. The usual one is the Wellman producer (fig. 166). It is built in a cylindrical riveted jacket which allows the using of a forced draft, usually a steam jet injector. This supplies gas to the furnace under a slight pressure which is important for good working.

The Tessié gas producer (a. I. M. E. XVIII, 27) has no grate bars, and the fuel rests on the brick bottom in which are channels for admitting air or a steam jet.

The Taylor producer (fig. 167) has no grate bars, but a revolving dome shaped plate (A, fig. 167). An air blast is driven through this into the centre of the fire. The producer has a water-jacket (D, fig. 167) instead of a brick lining.

General Observations.

The openhearth charge cannot be made up of steel scrap alone because the carbon would be too low when it was melted. When steel scrap cannot be had the pig and ore process can be used. The bath is very high in carbon, and it takes a long time for it to boil out, and

Pass.	Source of heat		Destination of heat				Balance available.
	Comb.	Regenerative Chambers	Bottom Walls	Regen. bricks	Radiation	Waste gases	
			c_1	d_1	e_1	f_1	$a_1 b_1 - (c d e f)$
1	a_1	b_1					
2	a_2	b_2	c_2	d_2	e_2	f_2	
3	a_3	b_3	c_3	d_3	e_3	f_3	

requires much ore which makes too much slag. High Si. (about 1.00%) can be gotten rid of only by some preliminary process such as the Talbot process (Journ. I. & S. I. 1892, II, 469) in which molten pig is poured through a mass of melted basic slag contained in a deep vessel. The Si. unites with the FeO leaving the pig nearly free of it; some P. is also removed.

On account of the objections to the pig and ore process, direct processes, such as the Eames process (see pps. 65,66) and the Adams-Blair are used to produce iron sponge. In the Adams-Blair process ore is charged into a furnace having narrow vertical chambers; natural gas and preheated air (heated in regenerators on either side) pass laterally through the layers of ore in the chambers. The ore is reduced to metallic iron and collects in a ball of iron sponge which is dropped through a bottom door onto the hearth of an open-hearth furnace and it here takes the place of so much scrap in making open-hearth steel.

In places where scrap is abundant and pig iron scarce, the necessary amount of C. for the bath is sometimes obtained by mixing coke dust in with the steel scrap, using no pig iron at all.

The waste in the open-hearth process is less than in the Bessemer because the materials have less C. and Si. to be burned out, and the oxidation of Fe. is also less. The loss is 5-7%. The cost for labor is generally higher because more work is done by hand and the operation is slower.

Metallic aluminum is sometimes added in the ingot molds while casting (Al. = .01 to .04%). It is thought to prevent blow holes, and in case of soft steel ingots for sheet steel is said to make it less liable to blister.

Open-hearth steel castings are poured into molds somewhat similar to those for cast iron, except that the facing must be of pure silica ground fine, to prevent the steel from burning into the facing.

Increasing Si. in the steel prevents blow holes by increasing the solvent power of the metal for gases. It also clears the bath of dissolved iron oxide, which, if present during the casting, reacts with the C. of the recarburizer producing CO which boils out, making spongy metal.

Fuel Gas.

Bituminous coal is most commonly used in the producer for making gas. Producer gas necessarily

contains nearly 60% of inert N. so that it is a weak fuel. Natural gas is a strong fuel but occurs in only a few favored localities. Producer gas from anthracite is even weaker than that from bituminous coal because it has no illuminating hydrocarbons. At steel melting temperatures the radiation from an illuminating flame produces a good part of the high temperature. For heating ingots where a lower temperature is used this difference in favor of the illuminating flame over the colorless one is less, and at the still lower heat used for boiler firing it disappears altogether (A. I. M. E. XXII. 380). A gas made by vaporized petroleum mixed with dry steam and forced through a red hot metallic retort is used, as in the Archer process. It is not however a fixed gas but a mixture. A high sulphur bituminous coal should not be used for producer gas because S. may be absorbed from the gas by the metal.

In the Wellman gas producer (fig. 166.) there are three zones of action, (1.) ash zone, (2.) combustion zone, (3.) and the distillation zone. When the mixed air and steam are blown in, the following reactions take place ——

$$C + 2O = CO_2, \quad CO_2 + C = 2CO, \quad H_2O + C = CO + 2H.$$

The heat from burning C. to CO distils off the hydrocarbons. The resulting producer gas will have about the following composition — CO = 22.8%; H = 8.5%; CH_4 = 2.4%; C_2H_4 = .4%; CO_2 = 5.2%; O. = .4%; N = 60.3%. The calorific value of 1 cu. m. of this gas is 1170 calories (C°) and 1000 calories are developed by .855 cu. m. which produce in burning 1.602 cu. m. of products of combustion. Water gas, having 50% CO and 50% H, requires .353 cu. m. to develope 1000 calories, and produces 1.019 cu. m. of products. From this it is seen that the areas of the gas and air ports of a furnace must be proportioned to the volume of the outgoing waste products rather than to that of the incoming gases

In running the producer there is a loss of some of the heat units contained in the coal. Having a coal with a heat value of 8198 calories (C°) per kilo these losses are;- in ashes 6% loss; in latent heat of volatilization 7%; in decompostion of steam 4.5%; in radiation 4.5%; in sensible heat of gas 13%; total loss = 35% or 2879 calories (A. I. M. E. vol. XXII, 378).

The amount of coal used per ton of ingots produced is from 800 to 1200 lbs.

Sizes of Open-Hearth Furnaces & cubic capacity of Regenerative Chambers.

Location.	Capacity.	Hearth Length & Width.	Effective Cubic Contents of Space filled by brick in each chamber	
Pottstown, Pa.	10 tons	15 x 10 feet.	650 cu. ft.	Basic lined
Staffordshire Eng.	10 "	16½ x 10½ "	—	" "
Swedish.	10 "	—	883 " "	Each chamber = 2.5 cu. m. per ton of steel made at a cast.
Pittsburg Lash Furn.	15 "	18 x 15 "	—	Elliptical hearth.
Johnstown, Pa.	17"	diam. = 12 "	514 " "	Pernot Revolving hearth - silica lined.
Pittsburg Lash Furn.	25 "	20 x 16 "	—	Elliptical Hearth Journ. I. & S. I. eh. vol. 90, 279.
Johnstown Pa.			365 " "	Siemen's Heating Furnace.

Open Hearth Steel.
Elements of Cost of a ton of Steel Ingots (2240 lbs.)

Locality.	Materials							Labor.	Officials & clerks.	Fuel.	Supplies & Repairs.	Taxes.	Total.
	Pig-iron.	Scrap.	Ferro-manganese.	Other	Total.	Value of scrap etc	Net.						
United States.	$2.813	$5.375	$.650	$ a. 3.375	$22.213	$1.700	$20.513	$3.000	$.250	$1.900	$1.700	$.025	$27.388
Cont. of Europe	$13.093	(Cost of all materials included in pig)			13.093	.113	12.980	.976	.108	1.124	1.563	.015	16.766
Grt. Britain	8.275	4.251	.415	b. .670	13.611	.373	13.238	1.589	.068	.880	1.083	.009	16.867

a. = Extra puddled muck bar iron.
b. = iron ore.
These costs are for 1889.

From "Sixth Annual Rep. Com. of Labor," Carrol D. Wright, 1891, p. 156.

Cost of Open Hearth Steel Ingots.
(In U.S. - S.W.C. - 1894)

Low Grade.

1/3 ton Bessemer pig at	$11.50 per ton	= $3.84
2/3 " scrap	" 12.00 "	= 8.00
Loss		= .75
Labor, fuel, refractories		= 6.00
		$18.59

High Grade.

1/3 ton low P. pig @	$17.00	= $5.67
1/3 " scrap.	12.00	= 4.00
1/3 " puddled bar	20.00	= 6.67
Loss		= .82
Labor, fuel, etc.		= 6.00
		$23.16

By this process, which is still used abroad, cement or blister steel is made from wrought iron. The purest wrought iron is heated to redness while completely surrounded with charcoal, and is maintained at that temperature 7 to 9 days; the iron takes on a certain amount of carbon and is then called cement or blister steel. These bars of blister steel cut, piled, heated, and rolled make shear steel; if shear steel be cut, piled, heated and rolled a second time it is called double shear steel.

If blister steel be cut up, melted in a black-lead pot, and poured into an ingot it is called cast steel or crucible steel.

The metal used at Sheffield, England, is wrought iron in bars 8" x ¾" which is derived by the Walloon process from the pure Swedish Dannemora pig iron. (see page 67.)

These bars are laid in layers in the pots with charcoal, smaller than ¾" in size, above and below each layer. The top is cemented on with grindstone waste; a test bar is placed at one end so that it may be withdrawn, examined and returned. The pots are made of slabs of fire stone. Seven days are required to heat up the furnace, and then it is kept seven to nine days at this high heat (the temperature of the pots is about 1170°C.); it takes seven days for it to cool down. Hammered bars

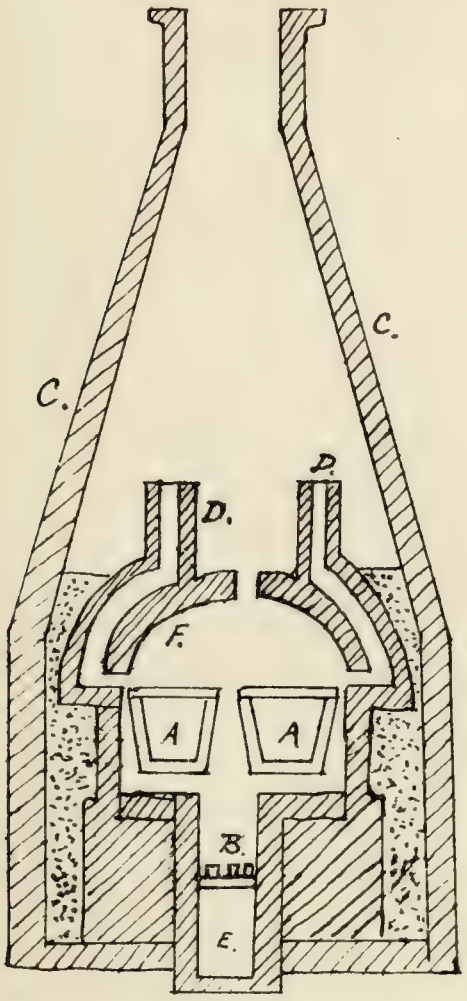


Fig. 168.
Cross Section

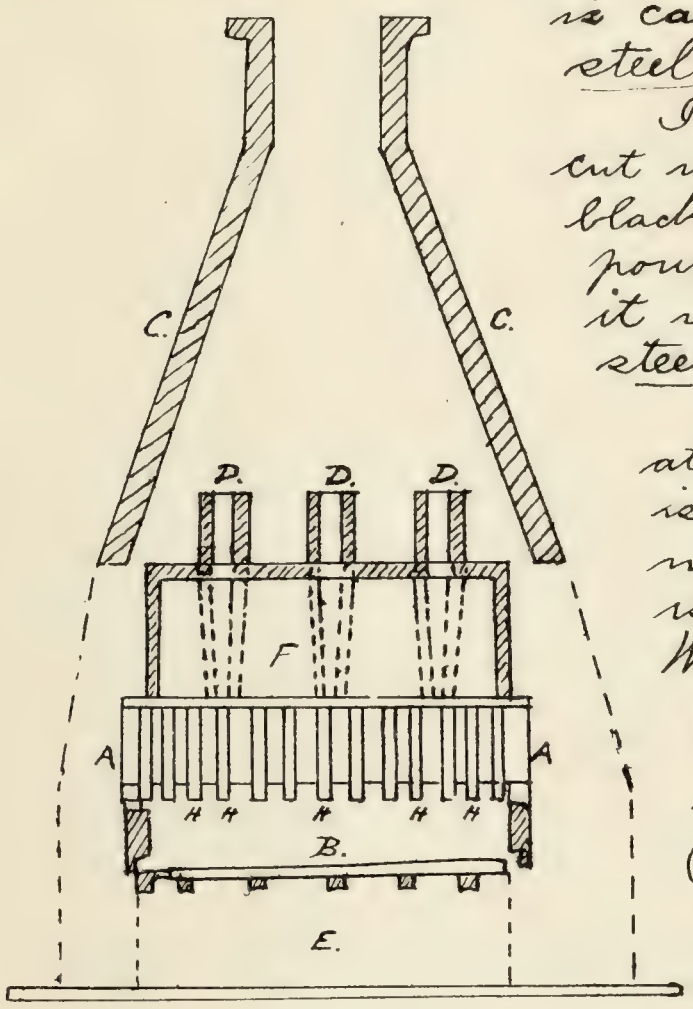


Fig. 169.
Longitudinal Section.

Cementation Furnace (Wedding, "Schmiedbaren Eisens", 1875. pp. 576, 578.)

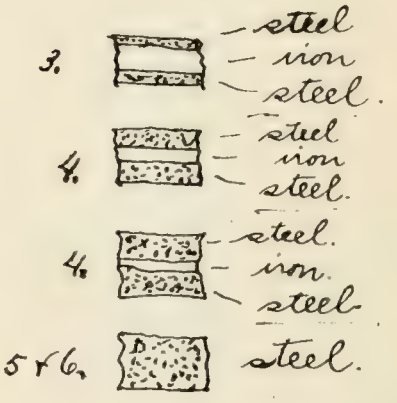
A = Steel-pot or chest 3'x3'x12'
B = Fire-place and grate.
C. = Outer dome or stack
D = Lesser stacks.
E. = Ash pit.
F. = Interior dome.
H. = Horizontal and vertical supports and props for pots.

are preferred to rolled bars for this process.

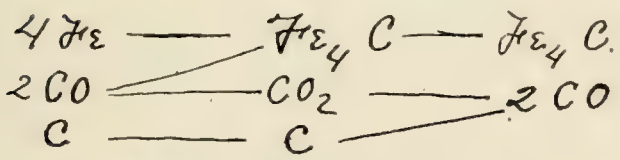
When removed from the pots the bars are more or less converted into steel leaving less or more of a plate of unconverted wrought iron in the centre.

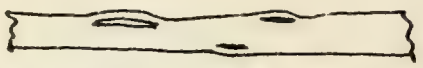
The heats are named according to the amount of conversion.

1. Spring heat	0.5% C.	large iron centre.
2. Country "	0.63 "	less " "
3. Single Shear "	0.75 "	equal iron & steel.
4. Double " "	1.00 "	less iron.
5. Steel through "	1.25 "	iron gone.
6. Melting "	1.50 "	" "



Reactions of the Process.





Bar of steel showing blisters.

These bars are more or less blistered on their surface, supposed to be due to increased size of converted layer. As already stated shear steel is converted steel, cut, piled, heated, and rolled. The final bar will therefore contain fibres of steel and fibres of iron laid together.

"Aired" bars are those which have been exposed to leaks of air. "Glazed" bars are those which are slightly melted. Neither are good for steel making.

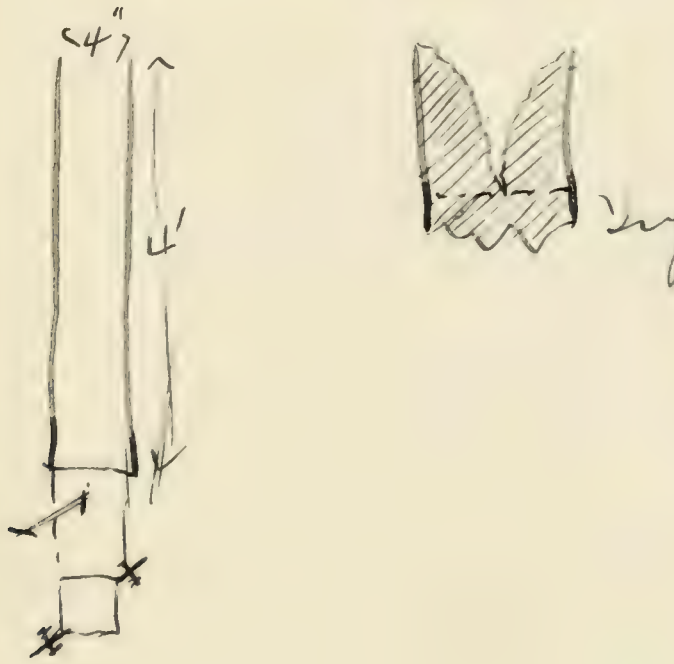
The Crucible Process.

The crucible process for making steel consists in melting down small charges of bar iron with charcoal, puddled bar and charcoal, or blister steel in clay or graphite crucibles holding from 50 to 85 lbs. each. The charge after being melted is allowed to stand for a time (called "killing") when it is poured into small molds. Crucible steel is used only for cutting tools and for purposes where a high grade is necessary, such as for razors, surgical instruments, etc., requiring to hold a fine edge, and for metal cutting tools needing a combination of hardness and toughness. Therefore only the purest melting stock can be used; it must be very low in P. and in S. It may however be of either high carbon (blister steel, etc.) or low carbon (Swedish bar iron, or puddled bar), and the amount of carbon in the finished steel regulated by adding more or less C., in the form of charcoal, to the crucible charge. This is absorbed during the melting (see Cementation p. 117.). When using graphite crucibles considerable C. is also absorbed by the metal from the crucible.

Melting 3 hr.

Killing 45 min. – absorption of Si (½)

Teeming pouring.



There are several different methods of procedure based on the kind of stock used (Howe, "Met. of Steel", p. 296.):-

1. Huntsman's, the original method, in which small pieces of blister steel or other highly carburetted steel are melted alone, or under a layer of glass.
2. Heath's modification of Huntsman's consists in adding oxide of Mn. and charcoal to the charge. The Mn. is partly reduced by the charcoal during the operation, and improves the quality of the steel. This is said to be the prevalent method in Sheffield, Eng.
3. The Carburizing-fusion method in which pieces of bar iron or puddled bar are used for melting stock, and the desired carbon in the ingot obtained by the addition of charcoal to the charge, is the common method in this country.
4. Uchatius, or Swedish method, consists of melting granulated pig and iron ore together. This needs very pure pig, and is not much used.
5. The pig and scrap method consists in melting wrought iron, or steel scrap, together with pig iron.
6. The Mitis process (see page 124) is also a crucible process. The charge, originally constituted in any of the above ways, is tranquilized by the addition of ferro-aluminum immediately after fusion, and is teemed a few minutes later.
7. The basic process of fusion in crucibles made of basic material is likely to be tried in the future.

The melting furnaces used are of three kinds:-

1. The simple shaft furnace (Howe, "Met. of Steel", 300; Wedding, 635; Percy, 831) using either anthracite or coke.
2. Siemens regenerative crucible furnace (Howe, p. 301.) (Fig. 170.)
3. Nobel's Petroleum furnace. (Howe, "Met. of Steel", 302.)

The process consists of three periods, melting, "killing", "teeming".

In American practice, using graphite crucibles, the crucible is charged cold, the larger pieces of bar iron being placed at the bottom, upon which is poured the recarburizing charcoal and also a little oxide of Mn., and sometimes also a little salt or ferrocyanide of potassium. A cover is put on and the whole is put into the hot furnace, the crucible standing on a bed of coke or anthracite. In three hours the contents are melted, the cover is lifted, and by the

examination it is determined how long the "killing" period must be. The metal is gently boiling. The Swedish practice is to introduce small pieces of ferro-manganese at this point, no oxide of Mn. having been previously used.

The "killing" or tranquilizing occupies about 45 minutes more, during which time the metal is taking up Si. from the walls of the crucible. The Si. prevents blow-holes probably because it enables the steel to dissolve the gases present. The time of killing is determined by the judgement of the melter's eye. At the proper time, and also the proper temperature for casting or "teeming" the crucible is lifted out by hand, the cover removed, the slag skimmed off, and the steel poured carefully into split molds without spattering.

The ingots when cold are usually somewhat hollow on top and this part (sometimes 30% of the ingot) is cut off and remelted. This is called "topping" the ingot and by the fracture the amount of C. can be determined with the eye. When the carbon is between 1.0 and 1.5% a difference of 0.05. C. can be readily distinguished. The ingots are thus graded and then hammered into flat, square, or octagonal bars for different uses.

The graphite crucibles are made from a mixture of Ceylon graphite, air-dried fire-clay, and sand. The mixture varies but generally has 50% graphite. The mixture is ground in a pug-mill, allowed to stand a few days ("tempered"), and then the crucible is molded by being pressed into a wooden mold, dried, and then burned in a kiln, losing 10% of its weight, part of the graphite being burned out. Clay crucibles are made of a finely ground mixture of fire-clay with about 15% of coke.

In using graphite crucibles the carbon absorbed by the steel from the walls during the melt is about .25%; when ferro-manganese is also used in the mixture this increases to nearly 2.%. The increase of Si. is .20%; when ferro. is used it is .50%. In using clay crucibles the charge does not increase in carbon nor in silicon unless manganese be present.

The graphite crucibles can be used about 5 times, the charge being smaller each time because the wear is mostly at the level of the metal.

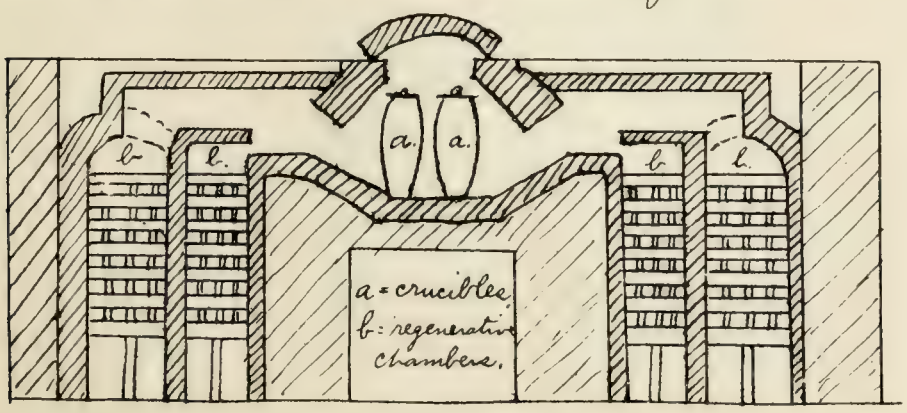


Fig. 170.
The Siemens Crucible Furnace.
(Wedding, "Schmiedbaren Eisens", 658.)

Crucible Steel (con.)

The control over the carbon to be obtained in the ingots is not so good as in case of either Bessemer or Open-Hearth, because it is so much influenced by the time of killing, the carbon of the crucible walls, etc.; but the grading and selection of the steel is very exact after the ingots have been "topped". An ingot with the desired carbon is thus easily obtained (between 1.0 and 1.5% C. as close as the nearest .05%)

Comparison of Crucible, Bessemer and Open Hearth.

The Crucible process being carried on in a closed vessel and the metal protected from the sulphur gases of the fuel, its superiority over both Bessemer and Open-Hearth comes from the following reasons:— It has low P., low S.; free from iron oxide; contains less gas (N, O, H.); has none of the rarer impurities, (As. and Cu.); has high C., and high Si. (probably.). As soon as all of the more obscure facts have been found out, it is probable that equally good steel can be made in the Open-Hearth furnace when using the same raw material.

Crucible steel furnishes the finest grades of cutlery and machine tools.

Razor temper	1½ % C.	easily burned, scarcely to be welded, takes extremely hard temper.
Saw file temper	1⅜ " "	less " " " " hard temper.
Tool temper.	1¼ " "	" " " difficult to weld " " "
Spindle temper	1⅛ " "	" " " " " " " "
Chisel temper	1 " "	" " " less " " " " fair "
Set temper	⅞ " "	much " " " comparitively easy to weld " tempers somewhat.
Die temper	¾ " "	" " " " " " little.

Prevention of Rust on Iron.

Rust is caused ordinarily by the meeting of $H_2O + O + CO_2 + Fe$; any one of these being absent rust does not take place. This is not intended to cover all cases of sea water, corrosive oils, chemicals, etc.

Tinning. Pure iron sheets ("black sheets") are scoured clean, dipped in acid, dipped in grease and in molten tin; this gives a coating of tin. Sn is generally negative to iron hence only preserves it till the film is scratched or broken, then iron rusts faster than if the tin were absent.

Galvanizing. Iron sheets are cleaned by acid, scoured, dipped in molten zinc coated with $ZnCl_2$ and NH_4Cl, and thus coated with zinc. Zn is positive to iron, and hence protects the latter after it is scratched or partly torn off.

Nickel Plating. The iron is cleaned and put in a bath of ammoniacal sulphate of nickel, and a strong electric current (about 3 volts?) coats the iron. It gives a hard durable coating electro-negative to iron, but does not easily scratch or tear.

Tar for cast iron - pipes, etc., dipped in molten tar are preserved for a very long time. Wire ropes in "acid" mines are protected by a coating of tar and lime.

Paints. Linseed oil on oxidation forms a rubber-like substance which the color may or may not help to produce; red lead helps to oxidize it. It has great preserving power.

Russia sheet iron (probably) The purest iron sheets are wetted, dusted with charcoal, piled, heated, and hammered; this is repeated four or more times. The water oxidizes, and the C, CO, and H reduce - the result is a magnetic (Fe_3O_4) coating on the iron, a very good preserver from rust.

Bower-Barff Process — Castings or wrought iron pieces are treated in a furnace (see a.J.M.E. XI, 338) say 40 minutes to an oxidizing atmosphere ($2Fe + 3O = Fe_2O_3$) then 20 minutes to reducing flame ($3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$) whereby the ferric oxide layer is changed to a layer of magnetic oxide (Fe_3O_4).

Safe plates; plates of hard + mild steel rolled in mill. Hard for tools + soft to resist cracking.

to 125
like H

Hadfield's Manganese Steel Process.

If Mn. in steel be raised to 2% it becomes brittle and worthless. When further raised to 14% the metal is very tough and very hard. Ferromanganese is melted with carbon steel until the Mn. is brought up to this point.

Nickel Steel.

Nickle steel is made by adding metallic nickle, ferro-nickle or nickle ore to the open-hearth bath, and the Ni. is alloyed with the carbon steel to any desired extent increasing its density and elasticity.

Chrome Steel.

Chromite is smelted in brasqued crucibles with charcoal and the resulting ferro-chrome, which has 40% of Cr. and 48 % Fe, is used for making chrome steel by melting it in a crucible with bar iron.

Harvey Process for Hardening the Face of Armor Plate.

The face of the plate of low carbon steel is covered over with a layer of charcoal dust or coke dust and the plate heated red hot in a furnace. The carbon is absorbed into the steel face (see cementation process page). The plate then has a low carbon back and a high carbon face. This is still further hardened by spraying water upon it. The extremely hard face prevents the penetration of the projectile; the soft back prevents the plate from cracking under the blow, (Jour. I. & S. I. 1894, I, p. 564.)

Sebenius Process for Preventing Blow-holes.

Ingot molds are suspended on trunnions upon a frame work which may revolve about a central vertical shaft. After filling the molds the machine is turned at 120 revolutions per minute, and the filled molds swing out to a nearly horizontal position. The metal tends to occupy the space farthest away from the centre. This process makes the steel more uniform in carbon and prevents blow-holes. (Journ. I. & S. I. 1894, I, p. 555.)

Electric Welding of Rail Joints.

In order to obviate the trouble with rail joints especially in street railways, A. J. Moxam of Johnstown, Pa., has welded rail joints with the Thomson electric welding machine. A piece of track 3000 ft. long was made without joints, and gave no trouble from expansion when the rails were held by the street paving. (Journ. I. & S. I. 1894, I, p. 562.)

Coffin Process for Railway Axles.

The axles after forging are heated to softness (1300° F.) which is called the "W" temperature. Then they are quenched in water to dull red (the "V" temperature.), and allowed to cool

down from this gradually. This makes the crystallization fine and uniform, and increases the elasticity without reducing ductility (Journ. I. & S. I., 1894, I, 564)

	Limit of elasticity	Tensile strength.	Elongation.
Before treatment	30,000 lbs. per sq. in	71,520 lbs. per sq. in.	24.5 %
After "	44 000 " " " "	72,020 " " " "	24.07 "

Fluid Compression (Whitworth.)

Steel for gun tubes and armor is solidified and cleared of blow holes at Whitworth's Gun Works (England.) and at Bethlehem Works by fluid compression. The steel is cast in strong molds which are quickly brought under a hydraulic press. The plunger descends onto the top of the still liquid ingot, and it is subjected to a pressure of 7000 tons while it is solidifying. This squeezes out a part of the contained gases and distributes evenly the contraction strains of the cooling ingot. Such treatment makes the ingot more solid (Howe "Met. of Steel", 105; Journ. I. & S. I. 1894, I, p. 553.)

Hammering and Hydraulic Press Forging.

In the forging of ingots for armor plate, gun tubes, marine shafting, etc., very large steam hammers are used (like the 125 ton hammer at Bethlehem.) Instead of a hammer hydraulic press forging is much used. There are presses of 5000 tons capacity at Bethlehem. The squeeze exerted upon the piece is thought to penetrate deeper into the mass with hydraulic forging than with the blow of the hammer, and therefore leaves the piece with more uniform strain.

Segregation.

The C., P., S., and Mn., sometimes have a tendency to concentrate in the centre and upper parts of ingots while they are solidifying, giving ingots which are not uniform. This is especially marked if the ingot is cooled very slowly or if there be large amounts of the elements present. (Howe, "Met. of Steel", p. 202; Stubbs, Journ. I. & S. I. 1881, I, 199.)

Occlusion of Gases.

Parry found that gases, especially H. and CO, exist in steel, wrought iron, and cast iron in some form of combination not well understood. He heated steel in vacuum to 1000° C. and collected 70 volumes of gases per volume of steel, consisting of 37.2 vols. CO, 32.+ vols. H, and 1.12 vols. CO_2 (Howe "Met. of Steel", p. 108; Journ. I. & S. I. 1871, II, p. 240.)

Burning or Over-Heating of Steel.

When heated to a temperature above that of softness ("W") and just below the melting point, a piece of steel becomes coarsely crystalline, the crystals having weak cohesion.

Burning Steel (con.)

If rolled or forged hot it breaks up having no toughness. When cooled it is very brittle, and may be broken short off by a sharp blow; the fracture is brilliant and glistening. The C. is not burned out nor is oxygen absorbed. Soft steel is sometimes thus injured by this crystallization. It may be restored by heating the cooled piece to a bright red heat and cooling slowly under a layer of lime or sand (annealing), or by quenching in water (hardening). (Howe, "Met. of Steel", p. 200.)

Punching, Cold Working, Cold Rolling, Wire Drawing.

In these operations an effect of crystallization somewhat similar to the above is produced. In punching holes in plates for boilers and in bridge and roof plates, the metal surrounding the hole is found to be injured to the depth of about an eighth of an inch. This must be either restored by heating and annealing or else removed by drilling out the hole. Cold rolling and wire drawing increase the hardness and tensile strength but diminish (sometimes more than 50%) the ductility. This must be restored by annealing before the wire can be drawn through the die again (Howe, "Met. of Steel", pp. 215, 232.)

Mitis - Castings from Wrought Iron or Steel.

By this process castings which are very tough are made from wrought iron which is melted in crucibles. A small piece of aluminum is added to the liquid iron and the mold filled as in making steel castings. The aluminum lowers the melting point, and also prevents blow-holes. (A. I. M. E. XIV, 773.)

Effects of the Elements in Steel.

(Howe, "Met. of Steel," p. 9.)

Carbon.

Carbon exists in steel in two forms as Hardening Carbon and Cement carbon. Up to 1.5% it increases tensile strength, and compressive strength and raises the elastic limit, and decreases the malleability, per cent. of elongation, and the welding power.

Silicon.

Silicon increases hardness, tensile strength, and solidity; and prevents blow holes. Too much makes steel brittle if other elements are high. From .3 to .5% Si. would be a maximum.

Manganese.

Manganese prevents hot shortness, removes and covers up effect of sulphur. It removes iron oxide, prevents blow holes, and increases toughness, elongation, and tensile strength. Too much Mn. (over 1.5%) makes steel

Effect of the Elements in Steel (Con.)

brittle when cold, especially after quenching in water. (See Hadfields' manganese steel page 122 for high Mn.)

Sulphur.

Sulphur causes hot shortness especially at a red heat, i.e., the metal is brittle under the hammer or rolls when hot.

Phoephorus.

Phosphorus causes cold shortness. It makes steel brittle, hard and liable to break under sudden shock. It increases elastic limit, and reduces elongation. These effects are increased by increase of carbon.

Copper.

Copper causes red shortness but much less than sulphur. 2% of Cu. makes steel worthless; 0.5% may be allowed in rails. Its effect is overcome by manganese.

Tin.

Tin destroys forgeableness and ductility both hot and cold; .1% Sn. makes steel worthless. Tin acts like phosphorus only worse.

Arsenic.

Arsenic has the same effects as sulphur.

Oxygen.

Dissolved oxides of iron make steel unforgeable. Oxygen is believed to increase tensile strength and diminish ductility (Journ. I. & S. I. 1894, I, p. 388.)

Special Steels.

(Mushet Steel.) — Tungsten Steel.—(Park Bros. "Imperial".)

Tungsten steel is very hard; more brittle than chrome steel; difficult to forge; self tempering. Quenching does not increase hardness. It is used for cutting-tools. W. = 6. to 10.% ; C. = 1.5 to 2.0%.

Chrome Steel - made by Chrome Steel Co., Brooklyn.

Chrome steel combines great hardness with forgeableness; used for burglar-proof safes. Cr. = 0.5% to 3.0%; C. = 0.5% to 0.9%.

Manganese Steel. (Hadfield's Mn. Steel.)

Manganese steel combines toughness, hardness, and strength. It cannot be machined but can be forged. It is softened by quenching. It is used for crusher jaws, car wheels, and stamp heads. Mn. = 14.% ; C. = 1.%

Special Steels (con.)

Nickel Steel.

Bethlehem and Carnegie Armor.

Nickel Steel has great density, elasticity, and strength, it does not corrode. It is used for armor plate and shells. Ni. increases elastic limit of steel (Journ. I. & S. I., 1893, I, p. 385). Nickel steel contains 4.0% Ni.; 0.3% C.; 0.7% Mn.; .02% P.

Aluminum Steel.

From .05% to .10% aluminum in steel castings reduces the melting point and keeps the metal liquid while pouring; it prevents blow holes.

Open-Hearth Steels — Grades and Composition.

Grade.	C.	P.	Si.	Mn.	S.	Ni.	Elastic Limit	Tensile Strength.	Percent of Elongation	Reduction of area.
							lbs.	lbs.		
Fire-box. } Boiler Plate.	.10%	.025%	.01%	.30%	.02%		30 000	50000-55000	30%	70.%
Flange. } Boiler Plate.	.12	.03	.01	.30	.03		35 000	50000-65000	30%	
Shell } Boiler Plate.	.12	.05	.02	.30				55000-65000	22.	
U. S. Cruiser plate.	.15	.06		.40				60,000	25	
Tank, and ship plate.	.16	.08		.40				below 75,000		
Marine shafts.	.18	.05		.60						
Bridge - Rivets	.20						38 000	68000	25.	45.
" - Tension members	.25	.05	.02	.60			40 000	72000	20.	40.
" - Compression "	.35	.08	.02	.60			50 000	80 000	15.	30.
Machinery - forgings	.30	.10								
H. Tire { England. / U.S	.35 / .50	.06		.60				85000		
Axle.	.40	.07	.01	.60				90000	12.	20.
Fork.	.70	.08	.15	.50			65 000	120000	10.	15.
Plow.	.50						60 000	100 000	11.	16.
H. Armor plate - Protective deck	.25	.07		.50				80000	18.	
J. " " Bethlehem (gun boat)	.27	.025		.74		4.17%		65000	12.	
H. " " face - gun boats	.75	.06	.12	1.00	.05					
H. Projectile - Terre Noire.	.50	-	.25	.55						
Rolls - steel castings	.60		.20							
Soft steel castings	.15	.05	.25	.75			46 000	70 000	20.	35
Hard " "	.60	.08	.25	.90						
Very hard " "	1.00		.27	.77			92000	150000	2.2	3.2
Spring.	.80	.08 / .10	.08	.60	.05		90000	150000	5.	5.
H. Gun barrels.	.25	.02	.23	.03						
H. Swedish gun barrels.	.40	.06	.30	.50						
H. Gun tubes - Woolwich.	.35	-	-	.31						
Cannon - Cammell - Eng.	.47	.059	.12	.40	.035					
" Midvale	.51	.029	.14	.84	.035		25 tons.	96000	15.	30.

H = Howe, "Met of Steel," p. 258.
J = Journ. I. & S. I. 1894, I, 588 (Government specification.)
The rest are from J. W. Cabot.

Composition of Steels.
Open-Hearth (con.)

Notice:- Boiler plate steel must be below .035% in P., low in S, low in Mn., and have enough C. to keep the tensile strength above 50000 lbs. Bridge steel is usually up to .08% P., but on account of the liability of high P. steel to break under sudden shock a more prudent limit is .05% P. Steel castings are better if made low in P. and the desired hardness obtained from carbon.

Bessemer Steels - Grades and Composition. (J.W.C.)

Grade.	C.	P.	Si.	Mn.	S. max.	Cu.	Elastic Limit	Tensile Strength	Per cent Elongation	Reduction of Area.
Sheets (black, galvanized or tinned	.10%	.10%	.01%	a. .35%	.08%		39000	65000	26.%	46.%
Wire rod, wire nails cut nails	.13	.10	.01	.40	.08		39300	65500	26.	45.
Bridge Rivets.	.15						42000	70000	23.	42.
Bessemer axles.	.18			.60			46000	75000	21.	36.
Beams, angles, tees.	.15						48000	78000	20.	
Bessemer bridge	.20	.08		.75			50000	80000	19.	30.
Machinery.	.25						51000	83000	19.	28.
Toe calks.	.28			.80			54000	90000	19.	26.
Light Rails. 56 lbs.	.32	.10	.05	.90 b.	.08		57000	95000	18.	25.
Medium " 85 "	.45	.08	.08	.85			60000	105000	10.	15.
Heavy " 100 "	.60	.06	.10 c.	.70 d.					.8.	

a. Soft Bessemer used for sheets should not have more manganese than enough to make it roll smoothly. In wire rod it must be harder in order to stand the draught in the rod rolling-mill.

b. & c. Steel for light rails has about .32% carbon. In heavy rails the C. is increased to .60%. In order that this may stand the drop test (see page 99.) the P. must be reduced and also the Mn. If Mn. is reduced below .75% the ingot may not roll well. This is improved by increasing Si. (d.)

Crucible Steels - Grades and Composition.

Grade.	C.	P.	Si.	Mn.	S.		Elastic Limit.	Tensile Strength.	Per cent. Elongation	Reduction of area.
Auger bit	.65%	%	%	%						
axe.	.95	.02	.08	.38						
Chisels.	1.00									
Rockdrill.	1.00			.29						
Files.	1.40	.03	.25		.01					

Composition of Steels.

Crucible Steel (con.)

Grade.	C.	P.	Si.	Mn.	S.		Elastic Limit.	Tensile Strength.	Elongation.	Reduction of area.
Guns - Krupp.	.50%	.04%	.11%	.16%	.03%					
Projectiles - Whitworth	.80	–	.06	.43	–					
" Krupp.	.55	.03	.23	.32	.008					
" Hotchkiss.	.55	.05	.05	–	.05					
Razors	1.50									
Jessups saws.	1.00	.025	.19	.30						
Taps and dies.	1.12									
Tool Steel - Swedish.	.70	.025	.03	.26						
" " Midvale, U.S.	1.00	.027	.10	.27	.015					
" " German.	.92	.02	.09	.12						
Pure Iron (Swedish.)	.07	.02	.04	.03	.02	Sp. gr. 7.863				

Notice that the best steels are very low in P. and S., and that tool steels are about 1.0% C. and rather high in Si.

A List of All the Bessemer Works in the United States

Corrected to March 1, 1894.

Capacity of converters expressed in tons of 2240 lbs.

Name of Works.	Where Situated	No. Converters	Capacity of each.
Pennsylvania.			
American Iron & Steel Works.	Pittsburgh.	2.	9.
Bethlehem Iron Co.	Bethlehem.	4.	7.
Cambria Iron Co.	Johnstown.	4.	11½.
Edgar Thompson Works } Carnegie	Bessemer.	4.	15.
Duquesne " } Steel Co.	Cochrane.	2.	10.
Homestead " } Ltd.	Munhall.	2.	10.
Columbia Iron & Steel Works.		2.	5.
Hainesworth Steel Co.	Pittsburgh.	2.	6.
Juniata Iron & Steel Works } Schoenberger & Co.	"	2.	6.
North Works. } Lackawanna	{Scranton}	3.	7.
South " } Iron & Steel Co.		2.	9.
Sickledale Iron Co.	Lebanon.	2.	3.
National Tube Works.	McKeesport.	2.	8.
North Branch Steel Co.	Danville.	2.	4.
Pennsylvania Steel Co.	Steelton.	2	7.
		3	8.
Pittsburgh Steel Casting Co.	Pittsburgh.	1.	10
Pottstown Iron Co.	(basic) Stowe	3.	10
Shenango Valley Steel Co.	New Castle	2.	8
Wellman Iron & Steel Co.	Thurlow.	2.	3.
Maryland.			
Maryland Steel Co.	Sparrow's Point.	2	20.
New York.			
Troy Steel & Iron Co.	Troy.	2.	10
West Virginia			
Riverside Iron Works.	Wheeling.	2.	5.
Wheeling Steel & Iron Co.	"	2	5
Kentucky.			
Ashland Steel Co.	Ashland.	2	5
Wisconsin			
West Superior Iron & Steel Co.	West Superior	2.	4.

Taken from "Directory to the Iron and Steel Works of the U.S." – 1894.

Name of Works	Where Situated	No. Converters	Capacity of each.
Ohio.			
Bellaire Nail Works.	Bellaire	2.	5
Cleveland Rolling Mills.	Newberg	2.	10
Laughlin & Junction Steel Co.	Irvingo Junction	2	5
Middleport Steel & Nail Works.	Middleport.	2	4
The Ohio Steel Co.	Youngstown.	2	10
The Otis Steel Co.	Cleveland.	2	5
The Johnson Co.	Loraine.	2?	10?
Illinois.			
North Works } Illinois Steel Co.	Chicago	2	6.
South "	So. Chicago	3	10
Joliet "	Joliet.	2	9.
Union "	Chicago	2	10
The Springfield Iron Co.	Springfield.	2	5
Valley Steel Co.	Belleville	2	4
Colorado.			
Colorado Fuel & Iron Co.	Pueblo.	2.	5
Small Works now Idle.			
E. & G. Brooke Iron Co.	Birdsboro, Pa.	2.	3.
Sharon Steel Casting Co.	Sharon, Pa.	1.	4.
Old Dominion Iron & Nail Wks.	Richmond, Va.	2.	3.
The Central Iron Co.	Chattanooga, Tenn.	1	6
The Solid Steel Co.	Alliance, O.	1	4
East Chicago Steel Works.	Hammond, Ill.	2	3
Premier Steel Co. (basic)	Indianapolis, Ind.	2	4
Clapp - Griffiths Works.			
Fremont Nail Co.	W. Wareham, Mass.	1.	3.
Oliver Iron & Steel Co.	Pittsburgh, Pa.	2.	2.
The Spang Steel & Iron Co.	" "	2.	3.
Valley Steel Co.	Belleville, Ill.	2.	3.
Robert - Bessemer Works.			
Chester Steel Casting Co.	Chester Pa.	2	1
The Chicago Horse Shoe Co.	East Chicago, Ind.	1	1½
Fowler Foundry Co.	Chicago, Ill.	1	2
Detroit Steel & Spring Works.	Detroit, Mich.	2	2
Union Steel & Iron Co. (partly built)	St. Joseph, Mo.	2.	3.

A List of All the Open-Hearth Steel Works in United States.

Corrected to Mar. 1, 1894.

Taken from "Directory to the Iron and Steel Works of the United States", 1894 compiled and published by the American Iron and Steel Association.

		No. of furnaces	Tons capacity
New Hampshire			
Nashua Iron & Steel Co.	Nashua.	1	10
Massachusetts.			
General Electric Co. (castings)	Lynn.	2	15.
New England Steel Works. (castings)	Worcester	1	4
		1	10
Tremont Nail Co.	West Wareham.	1	20
Washburn & Moen Co.	Worcester	1	12
		1	20.
New York.			
Buffalo Steel Fdry (castings)	Buffalo.	2	
Gatling Ordance Co (proposed.	"		
I. G. Johnson & Co. (castings)	Spuyten Duyvil	1	8
Syracuse Steel Fdry Co (castings)	Geddes.	2	10
New Jersey.			
Newark Steel Works.	Newark.	1	7
		1	15
Passaic Rolling Mill	Paterson.	2	20
Trenton Steel Co.	Trenton.	1	7
Taylor Iron & Steel Co. (Hadfields Manf. Steel & castings)	High Bridge.	1	7
Pennsylvania.			
The Bethlehem Iron Co. (S. nuts, armor & marine shafting)	So. Bethlehem.	1	10
		1	20
		2	40
Chester Steel Casting Co. (castings.)	Chester.	1	15
Eureka Cast Steel Co. (castings.)	Lansdown	1	20
Lukens Iron & Steel Co. (boiler plate)	Coatesville	2	20
The Midvale Steel Co. (Armor, plates.	Philadelphia.		
Norristown Steel Co. (castings.)	Norristown.	2	15
Pencoyd Iron Works. (plates, structural)	Philadelphia.	4	22
Penn Steel Castings & Machine Co.	Chester.	2	20
Phoenix Iron Co. (structural.)	Phoenixville.	4	15
Pottstown Iron Co. (basic, boiler plate)	Stowe.	1	10
Pottsville Iron & Steel Co. (structural.)	Pottsville	2.	20
Standard Steel Casting Co. (castings)	Thurlow	2	8
		2	20
Wellman Iron & Steel Co. (boiler plates)	" basic	2	15
		2	20
North Branch Steel Co.	Danville.	1	15
Pennsylvania Steel Co.	Steelton.	1	5
" " "	"	1	7
		2	15
		2	30
		6	50
Aliquippa Steel Works.	Aliquippa	1	12
Apollo Rolling Mills (sheets.)	Apollo.	2	20
The Aschman Steel Casting Co.	Sharon.	1	5
Black Diamond Steel Wks (Park Bros & Co.)	Pittsburgh.	5	25
Cambria Iron Co.	Johnstown	3	20
Carbon Steel Co. (Structural.)	Pittsburg	2	15
		6	30
Mackintosh, Hemphill & Co., Fort Pitt Fdry.	"	2	12
		2	20
(Homestead Steel Works. Carnegie Steel Co., Ltd.)	Munhall.	1	12
		6	20
	"	8	25
		1	35
Howe, Brown, & Co.	Pittsburgh.	1	20
		1	30
The Johnson Co. (Castings)	Johnstown.	1	2
Schoenberger & Co. (boiler plates.	Pittsburgh	1	7
Labelle Steel Co	"	2	12
		2	15
Latrobe Steel Works (tires - car & loco.)	Latrobe.	2	20
Leechburg Iron Works. (sheets)	Leechburg	1	15
The Linden Steel Co. (boiler plate)	Pittsburgh	2	15
		1	25
McKeesport Iron Wks (W. D. Wood Co.)	McKeesport.	2	20
Millvale Iron Co. Ltd.	Pittsburgh	2	15
National Separating & Tufj Co. (steel castings)	"	1	small
National Tube Works.	McKeesport	1	18
Pittsburgh Steel Wks (Anderson, Dupuy & Co.)	Charters.	1	20
Sharon Steel Casting Co.	Sharon.	1	5
		1	15
Singer, Nimick & Co. Ltd.	Pittsburgh	1	10
Soho Iron & Steel Wks. Moorhead McClean & Co.	"	2	15
Solar Steel Wks (Wm. Clarke Son & Co.)	"	2	12
The Spang Steel & Iron Co. (plates.)	Etna.	3	10
Totten & Hogg Iron & Steel Fdry Co.	Pittsburg	1	15.
West Penn Steel Wks (Jennings Bros. & Co.)	Allegheny	1	10.
Tennessee.			
The Central Iron Co. (basic - idle.)	Chattanooga	2	10.
Kentucky.			
Mitchell, Tranter & Co.	Covington.	1	7.
The Watts Steel & Iron Syndicate. (not completed.) (basic.)	Middlesborough	7	25
Alabama.			
Alabama Steel Works. (Sidle, basic)	Fort Payne.	2	15
Jefferson Steel Co. (sidle, basic)	Birmingham	1	15
Ohio.			
Burgess Steel & Iron Works.	Portsmouth	1	8
		1	10
Canton Steel Works	Canton.	1	25
		2	10
Cleveland Rolling Mill Co.	Cleveland	2	15
Cleveland Steel Casting Co.	"	1	10
Kellogg Seamless Tube & Mfg Co.	Findlay.	1	10
		1	25
The Lima Steel Casting Co. (castings)	Lima.	1	10
The Otis Steel Co. (boiler plate.)	Cleveland.	7	15
The Solid Steel Co.	Alliance.	1	3
		1	5
Springfield Steel Casting Fdry	Springfield	1	6.
Youngstown Steel Co. (1 - 10T Krupp washer - see note p. 76)	Youngstown.	1	20
Zanesville Iron Works.	Zanesville	1	10.
Indiana.			
Anderson Steel Casting Co.	Anderson.	1	10
Midland Steel Co.	Muncie.	1	20
Premier Steel Co.	Indianapolis.	2	15
Illinois.			
Chicago Axle & Spring Co.	Melrose.	1	8
		1	10
Illinois Steel Co. plates.	So. Chicago.	4	15
Norton Brothers.	Maywood	1	
The Sargent Co. (castings.)	Chicago.	1	12
Springfield Iron Co. plates. (1 Pernot furnace for Krupp washing)	Springfield.	2	20
Michigan.			
Muskegon Iron & Steel Co.	Muskegon	1	15
Minnesota.			
Ironton Structural Steel Co. (proposed)	Duluth.	3	23
Missouri.			
Shickle, Harrison & Howard Iron Co. (basic - machine castings)	St. Louis.	1	6
		1	8
California.			
Pacific Rolling Mill Co.	Potrero.	1	5
		2	18

Grand Summary of Iron and Steel Works of U.S. 1894. - from "Directory of I. & S. Works of U. S. 1894." (p. XII.)

	Number.	Annual capacity - gross tons. (2240.)
Completed Blast Furnaces.	519.	16,271,027
Completed Rolling Mills and Steel Works.	487.	
Single Puddling Furnaces (double furn. = 2 single)	4,715.	
Heating Furnaces.	3,054.	
Trains of Rolls.	1,690.	
Capacity of completed Rolling Mills.		12,477,890.
Completed Standard Bessemer Steel Works	43.	
Completed standard Bess. converters (35) 3 building	95.	
Capacity (built & building) in ingots & direct castings		1,740,900.
Completed Clapp-Griffith Works.	4.	
" " " converters.	7.	
Capacity " " "		146,500.
Completed Robert-Bessemer Steel Works.	4.	
" " " converters (2 partly built)	6.	
Completed Open-Hearth Steel Works.	81.	
Open Hearth Furnaces (189) (building 9)	189.	
Capacity (built & building) in ingots & direct cast		1,740,000
Completed Crucible Steel Works. (2 melts each heat)	48.	
No. of steel-melting pots which may be used at a	3,103.	
Capacity in ingots & direct castings		99,000.
Forges making Wrought Iron from ore	11.	
Capacity in blooms and billets.		17870
Pig and Scrap iron Bloomaries	14.	
Capacity in Blooms.		30 925

Bessemer	Rails
Open hearth acid	structural steel + tools
" " basic	better on acid work
Crucible —	best tools + responsible parts

Properties of Steel — from Howe's "Metallurgy of Steel."

Howe p. 1. Classification of Iron Metals by Committee of A. I. M. E. 1876.

Malleable.				Non-Malleable.
Cannot be hardened on sudden cooling. Iron		Can be hardened on sudden cooling. Steel		
Cast when molten into a malleable mass.	aggregated from pasty particles without subsequent fusion.	Cast when molten into a malleable mass.	aggregated from pasty particles without subsequent fusion.	
Ingot iron.	Weld Iron.	Ingot Steel.	Weld Steel.	Cast Iron.
Fluss Eisen.	Schweiss Eisen.	Fluss Stahl.	Schweiss Stahl.	Roheisen (Guss eisen).
Fer Fondu.	Fer Soudé.	Acier Fondu.	Acier Soudé.	Fonte.

Howe. p. 16. Effects of Carbon on tensile strength. 1.00% Carbon gives about the maximum on unhardened metal.

Carbon % =	.05	.10	.15	.20	.30	.40	.50	.60	.80	1.00	1.30
Tensile strength upper limit =	66000.	70000	75000	80000	90000	100000	110000	120000	150000	170000	115000
Tensile strength lower limit =	50000.	50000	55000	60000	65000	70000	75000	80000	90000	90000	90000

Effects of Carbon on elongation, maximum with carbon = 0%.

Carbon % =	.10%	.20%	.30%	.40%	.50%	.60%	.70%	.80%
usual upper limit =	29.%	25.2	23.	21.	—	10.	7.5	6.0
usual lower limit =	17.5%	15.	12.	—	7.5	—	2.5	1.5

Tensile Strength and Elongation. Tensile strength diminishes as elongation increases.

Elongation =	4%	6%	8%	10%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%	32%
(usual limits tensile strength) upper limit =	150000	138000	130000	122000	115000	108000	102000	98000	93000	88000	80000	77000	74000	71000	70000
lower limit =	111000	102000	94000	85000	80000	75000	70000	64000	59000	56000	52000	51000	51000	50000	50000

Effect of Carbon on Modulus of Elasticity.

Carbon. % =	.0 to .15	.15 to .25	.25 to .35	.35 to .75	.75 to 1.00	1.00 to 1.26
Modulus of elasticity maximum =	30 000 000	31 000 000	31 000 000	31 000 000	29 000 000	32 000 000
minimum =	22 000 000	25 000 000	25 000 000	24 000 000	23 000 000	25 000 000

Howe, p. 17. Compressive strength rises with Carbon.

Carbon. % =	.3%	.6%	.9%	1.2%
Ultimate compressive strength =	47513.	84827.	95207.	102173.
Elastic compressive strength =	40666.	52666.	58000.	61666.

The figures are pounds per sq. in. with a length = 8 diameters, probably square at both ends with flat supports.

Howe, p. 20. Unannealed steel is changed by hardening ± %.

Carbon %	Unannealed Steel. Tensile strength lbs. per sq. in	Elongation %	Elastic limit lbs. per sq. in.	Hardened Steel. Tensile quenched in water	oil	Elongation quenched in water	oil.	Elastic Strength, quenched in water	oil
.01 weld iron.	51262	—	——	+7.8%	—	-12.%	—		
.15 Terre noire steel	51520	32.5	24640	+22.	+26.%	-42.	-12%	+64	+81
.49 " " "	67200	24.8	33600	+73.	+60.	-90.	-52.	+100	+80
1.05 Cambria Open-Hearth.	145400	5.5	82810	—	+39.		+13.		+44

The Saturation point of iron with carbon is raised and lowered by other elements.

Silicon decreases the Saturation % { C. % 4.6% 2.88% 1.81%
Si % 0 5.47 9.80

Manganese increases " " " { C. 4.6% 7.00 %
Mn. .0 80.00

Hardness increases with % of carbon. Wire dies with 1.7% wear much faster than those with 2.37% carbon.

Fusibility increases with % of carbon. The apparent inconsistency in gray iron is due to the fact that the graphite is not in combination with the iron until after fusion.

Moderately rapid cooling raises tensile strength.
Very " " may lower " "
Oil hardening always raises tensile strength.
Water hardening usually lowers " "

Howe p. 23. Tempering Steel or Drawing the hardness.

Color	Temperature	Suited to Steel of Carbon %	Corresponding Uses.
White	—	Tungsten Steel.	hardest
Pale yellow	428° F.	—	lancets
Straw	446° "	1.5%	Razors — surgical instruments.
	450° "	—	Engravings, taps, dies, cutters. (First smoke by oil bath.)
Golden yellow	469° "	1.3%	Razors, pen knives, pocket knives, hammers, taps; reamers, dies for wrought iron, cast iron, copper, brass, etc. cold chisels for cutting steel
Brown	491° "	1.3%	cold chisels, shears, chisels, hatchets. (Strong dark smoke from oil bath.)
	500° "		
Brown dappled with purple	509° "		Axes, planes, lathe tools for copper. (abundant black smoke from oil bath.)
Purple	530° "		
	531° "	1.9%	Table knives, large shears, wood turning cutting tools, cold chisels for soft cast iron. Cold chisels for brass
Violet.			
Bright blue.	550° "		Swords, coiled springs.
Full blue	559° "		Fine saws, augers, etc.
	580° "		(oil bath can be lighted but goes out.)
Dark blue	600° "	.8%	Hand and pit-saws. cold chisels for wrought iron and copper.
Just visibly red hot in the dark			(Oil bath lights spontaneously.) Spiral springs. (oil bath burns rapidly.) {clock makers purposes}

For hardening where carbon is low, a high quenching temperature gives the greatest tensile strength. Where carbon is high a low quenching temperature gives the greatest tensile strength. Liquids for chilling steel arranged in the

order of their activity:— mercury quickest, brine or urine next, water next, then rapeseed oil, tallow, and finally coal tar is the slowest.

From all the facts Howe concludes:— For hardening
For greatest tensile strength with low C. steel quench rapidly in water from high temp.
" " " " " .+% C " " moderately " oil from strong yellow.
" " " " " high C. " " gently " " " " low temp.

Elongation is reduced by hardening more for high carbon than for low.
Elastic limit is raised " " " " " " " " "
Degree of hardening is increased by temp. of quenching and by % of carbon.

Howe p. 27. Annealing is almost the exact opposite of hardening in tensile strength, elastic limit and ductility.

Carbon.	Before annealing. Tensile str.	elastic lim.	elongation.	After annealing. increase = + decrease = — tensile str.	elastic lim.	elongation.
.80%	98624	66500	2.2	−12.7%	−29.0%	+150.%
.60 "	97887	47700	10.2	− 6.2 "	− 2.9	+ 25.
.40 "	75013	39200	17.9	− 5.7 "	− 7.0	+ 6.
.20 "	59940	35200	22.5	− 6.0 "	− 6.0	+ 1.3

Steel as often finished is cooled so rapidly that it is considerably hardened thereby, annealing removes this;—steel casting for example.

p. 28. Hardening followed by annealing gives:—
Slight increase of tensile strength. — Great gain in elongation.
Very great gain in reduction of area perhaps a little more than with annealing alone.
P. 26. — Annealing benefits thick pieces more than thin ones. Thick pieces have tensile strength diminished less and ductility increased more than thin.

Little is known about hardening and annealing. Carbon is thought to have two forms that are interchangeable, — Hardening Carbon, and Cement Carbon. At a red heat the carbon is nearly all in the hardening condition. If cooled in the ordinary way a large part of the C. goes over into Cement carbon. If quenched the carbon is caught and held in the hardening condition. If after quenching the hardness is partly drawn by heat (see page 131) then a portion of the hardening carbon is changed over to cement carbon. This theory is simply a hypothesis.

p. 34. manganese steel is slightly softer and decidedly tougher if suddenly quenched.

Howe, p. 36. Silicon and Iron. Silicon alloys with iron up to 30%. It lessens the power of iron to combine with carbon particularly at and just below the chilling temperature. It increases fluidity and fusibility; lessens blow holes; reduces oxide of iron and hence red shortness; hinders oxidation of iron at a high temperature, and probably also of carbon. Silicon affects welding —, hardening +, tensile strength +, brittleness +, red shortness +, but little if at all.

p. 36. SiO_2 is not reduced to Si by C. or Fe. alone but by C + Fe rapidly. Silicon is sometimes thought to be only tolerable with low carbon. Howe thinks otherwise. Steel castings ordinarily run with from .2% to .5% of Si., and when annealed they compare favorably with forgings even for carbon .7% and 1.0%.

Howe p. 39. Effect of Silicon on Tensile Strength and Elongation.

Carbon.	Si. .0 – .05%		Si. .20 – .30%		Si. .40 – .50%		Si. .50 – .60%		Si. .70 – .80%	
	Tensile	Elongation.	Tensile	elong.	Tensile	elong.	Tensile	elong.	Tensile	elongation.
.0 – .10%	59181.	27.%	55000	25.%	—	—	—	—		
.10 – .20	60636.	26.	74000	24.4	83700	18.5%	—	—		
.20 – .30	70000	23.	67000	21.	—	—	82000	21.%	116000	19.%
.40 – .50	81600	8.6	104300	12.3	98700	13.				
.50 – .60	88500	3.	130000	14.	104000	10.				
.70 – .80	126000	4.4	131300	3.4	79000	1.3			Si. = .60 – .70%	
.80 – .90	149000	3.	139000	81	147000	3.				
.90 – 1.00	134000	2.	130000	5.	—	—	—	—	81000.	1.1%

Howe. p. 41. Silicon increases tensile strength in cast iron.

Si.	G.C.	C.C.	T.C.	Tensile strength.	Crushing strength.
.19	.38	1.60	1.98	22720	168700
.45	.10	1.90	2.00	27580	204800
.96	.24	1.85	2.09	28490	207300
1.37	.50	1.71	2.21	31440	183900

As Si. rises above 1.4 graphite rises rapidly; later it falls off again, while tensile and compressive strength both decline uninterruptedly.

Howe p. 42. Effect of Manganese is thought to
increase tensile strength slightly; diminish fusibility.
" hardness, " ductility.
" fluidity.
" elastic limit.

Between 1.5% and 2.5% Mn. Steel is made brittle by it.
at 8.% Mn. " " astonishingly ductile.
" 8. to 10% Mn. Steel is extremely tough and is used for cutting tools without quenching.

p. 48. Hadfield's Steel contains from 7. to 30% of Mn.

Mn.	C.	Si.	S.	P.	Tensile str.	elongation.	
9.8%	.72%	.37%	.06%	.08%	106490	22.%	
					119054	28.9	
12.5	—	—	—	—	246480	—	Hard drawn wire.
					107520	20.%	" " annealed.
17.5	.80	—	—	—	Hardly cut by carbon steel, quenched in water, it bent double without cracking.		
18.0	—	—	—	—	can be forged, but with difficulty.		
9. to 10.	—	—	—	—	hard to cut by carbon steel.		

See also Howe p. 361.

Probably: rising from 2.5% ? Mn. to 6% ? hardness greatly increases, strength and ductility diminish.
rising from 6.% 8. max. Strength and toughness rapidly increase; hardness slightly diminishes.
at about 14.% A maximum of strength and toughness is probably reached, combined with hardness so great that the steel can hardly be machined.

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(for abbreviations see page 148)

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Exam.

1 Blast Furnace process
2 Foundry
3 Puddling
4 Acid Bessemer
5 " Open-hearth
6 Basic " "
7 Cementation Steel
8 Crucible "

Crude Material

Furnace

Suppl. app. plant

Routine of Process

Products

Market Prod.

Classification of working Prod.

Use-characters of Mark. Prods.

1
2
3
4
5
6
7
8

1

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